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**Author(s):** Finell, Eerika; Tolvanen, Asko; Ikonen, Riikka; Pekkanen, Juha; Ståhl, Timo

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# Students' school-level symptoms mediate the relationship between a school's observed moisture problems and students' subjective perceptions of indoor air quality

Eerika Finell<sup>1</sup>  | Asko Tolvanen<sup>2</sup>  | Riikka Ikonen<sup>3</sup>  | Juha Pekkanen<sup>4,5</sup>  | Timo Ståhl<sup>6</sup> 

<sup>1</sup>Faculty of Social Sciences, Tampere University, Tampere, Finland

<sup>2</sup>Methodology Center for Human Sciences, University of Jyväskylä, Jyväskylä, Finland

<sup>3</sup>Department of Welfare, Finnish Institute for Health and Welfare, Helsinki, Finland

<sup>4</sup>Department of Public Health, University of Helsinki, Helsinki, Finland

<sup>5</sup>Environmental Health Unit, Finnish Institute for Health and Welfare, Kuopio, Finland

<sup>6</sup>Department of Welfare, Finnish Institute for Health and Welfare, Tampere, Finland

## Correspondence

Eerika Finell, Faculty of Social Sciences, Linna, 33014 Tampere University, Finland.  
Email: eerika.finell@tuni.fi

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## Abstract

Moisture damage can influence the subjective assessment of indoor air quality (subjective IAQ) in various ways. We studied whether the frequency of symptoms reported across students at school level mediates the relationship between observed mold and dampness in a school building and students' subjective IAQ. To answer this research question, we tested a multilevel path model. The analyzed data were created by merging two nationwide data sets: (a) survey data from students, including information on subjective IAQ (N = 24,786 students); (b) data from schools, including information on mold and dampness in a school building (N = 222). After the background variables were adjusted, schools' observed mold and dampness were directly and significantly related to poor subjective IAQ (standardized beta ( $\beta$ ) = 0.22,  $P = .002$ ). In addition, in schools with mold and dampness, students reported significantly more symptoms ( $\beta = 0.22$ ,  $P = .023$ ) than in schools without; the higher the prevalence of symptoms at school level, the worse the students' subjective IAQ ( $\beta = 0.60$ ,  $P < .001$ ). This indirect path was significant ( $P = .023$ ). In total, schools' observed mold and dampness and student-reported symptoms explained 52% of the between-school variance in subjective IAQ.

## KEYWORDS

dampness, indoor air quality, indoor environmental problems, multilevel analysis, school, symptoms

## 1 | INTRODUCTION

There is growing recognition that indoor climate conditions in school environments are poor in many countries: classrooms are too crowded, ventilation is inadequate, and dampness and mold are commonplace.<sup>1-4</sup> The World Health Organization has insisted that

problems with schools' indoor environments should be taken seriously, because students spend many hours per day in these environments.<sup>5</sup> A large volume of literature has shown that poor indoor environments have especially adverse health effects on children, for example causing asthma.<sup>6-10</sup>

One relatively cheap way to track the quality of schools' indoor environments might be through questionnaires to students.<sup>11</sup>

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Previous research has analyzed whether students' subjective evaluation of indoor environmental quality reflects the objective knowledge received from inspections and measurements conducted in school buildings. The results have been somewhat varied. Some studies have not been able to demonstrate a relationship, whereas others have shown that students can relatively accurately evaluate the indoor air environmental quality of their schools.<sup>12-17</sup> These inconsistencies point to an urgent need to understand more deeply which factors affect students' evaluations.

It is likely that there are individual differences in how much attention students pay to their school's indoor environmental quality. It is well known that learning and individual characteristics play important roles in how people process sensory stimuli.<sup>18-21</sup> For example, people who have long-term everyday experience of various odors have greater odor awareness and better ability to identify odors than those who do not have such experience.<sup>22,23</sup> Female and older children might be more sensitive to odor than males and younger children, although these findings have not been entirely consistent.<sup>24,25</sup>

In addition to cognition, emotions also affect sensory perception.<sup>26</sup> People are surrounded by numerous sensory stimuli competing for their awareness and cognitive resources. Among these stimuli, people tend to be more aware of those that are emotionally meaningful than of those that are neutral.<sup>27</sup> Especially negative emotions, such as feelings of threat and fear, have a strong impact on how people process sensory information.<sup>28,29</sup> For example, people who have experienced symptoms from poor indoor air might be more aware of indoor air quality than others, who might only notice it when it is brought to their attention by someone else.<sup>30,31</sup> However, what is considered a threat is often the outcome of a social process. People use information acquired from others' reactions to infer whether a stimulus should be categorized as potentially threatening, and whether they should pay attention to it.<sup>32,33</sup> In the context of schools' indoor environments, this means that students may process many kinds of information when they assess indoor environmental quality.

## 1.1 | The present study

This paper has two aims. Our first aim is to analyze whether schools' observed mold and dampness and students' perception of indoor air quality (subjective IAQ) are related to each other, using a large representative sample of students from more than 200 lower-secondary schools in Finland. Moisture damage is relatively common in schools. For example, it has been estimated that 20% of schools in the Netherlands, 24% in Finland, and 41% in Spain have moisture problems.<sup>34</sup> To the best of our knowledge, only one previous study has specifically focused on the relationship between schools' observed mold and dampness and students' subjective IAQ, showing no significant association between mold and dampness in school buildings and a change in subjective IAQ in a two-year follow-up study.<sup>14</sup>

Our second aim is to test whether this relationship is partly mediated by the frequency of symptoms that students report at school

## Practical implications

Information on IAQ problems experienced by a building's users often helps with the solution of potential IAQ problems. However, authorities should be aware that students' evaluation of IAQ is a complex process, and indoor mold and dampness may affect subjective IAQ not only directly but also via the prevalence of symptoms reported in a school.

level. Previous research has shown that students have more symptoms in schools with moisture damage than in schools without such problems.<sup>35-37</sup> In addition, based on the literature cited above, we suggest that the overall frequency of symptoms reported across students in a school may relate to students' subjective IAQ. We have not found any previous studies that test whether symptoms reported at school level mediate the relationship between a school's indoor air problems and students' subjective IAQ. Our conceptual model is visualized in Figure 1.

## 2 | MATERIAL AND METHODS

### 2.1 | Data and participants

The *student-level* data were obtained from the 2017 round of the School Health Promotion Study (SHP), a nationwide classroom survey. We focus on the eighth and ninth grades (ages 14-16 years). SHP has monitored the health and well-being of Finnish adolescents since 1996. It is conducted by the Finnish Institute for Health and Welfare (THL) with approval from the THL's ethical committee (THL/1704/6.02.0 1/2016). The data are gathered as part of the normal school day, and the students' parents and guardians are informed of the study. The students are informed of the aims and contents of the survey, and they have an opportunity to decline. Signed consent forms are not needed, since the survey is conducted anonymously. In 2017, the data were collected in April through a classroom

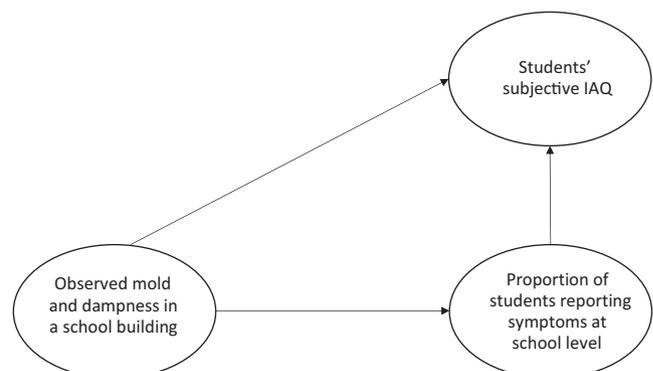


FIGURE 1 Conceptual model

survey during school lessons, and 84% of lower-secondary schools in Finland participated.

The *school-level* data were obtained from the Benchmarking System of Health Promotion Capacity Building's (BSHPCB) data collection in comprehensive schools in 2017. The BSHPCB is a nationwide benchmarking tool for local governments and schools to manage, plan, and evaluate their own health promotion activities and resources in basic education. The data collection form is filled in by the school's principal together with a student welfare team. The BSHPCB is run by the THL and the Finnish National Agency for Education. The data were collected between October and December 2017, and 91% of lower-secondary schools in Finland participated.

We included schools in the analyses on the basis of two variables from the BSHPCB. The first variable measured when the most recent inspection of the health and safety of the school environment and the well-being of the school community had been carried out. This inspection is required by Healthcare Act 1326/2010, which states that all schools in Finland must be checked every three years. This triennial official inspection is conducted in cooperation with the school's health service, representatives of the school (eg, the principal), representatives of the health authority, occupational healthcare, and occupational health and safety, and authorities responsible for the construction and maintenance of school buildings. The inspection is large-scale, and it should include all the possible factors (not only building-related) that might influence the well-being of the school community.<sup>38</sup> We have described the inspection focusing on building-related factors in detail elsewhere.<sup>39</sup> For our analysis, we selected only schools where an inspection had been carried out in 2016 or 2017.

The second variable measured whether mold and dampness had been observed in the school. We included in our analysis schools where 1) mold and dampness had been identified during the check and the problems had not been remediated or 2) no mold and dampness had been identified during the check. Schools with fewer than 10 students were excluded from the analysis (N = 51), as were those dedicated exclusively to children with special educational needs, such as children with severe learning difficulties (N = 89). We also excluded respondents who did not report their age, or who reported their age to be less than 14 (N = 340), as well as those who did not report their subjective IAQ (N = 315). The final data set consisted of 24,786 students from 222 schools. About 30% of these students were from schools with observed dampness and mold (7,312 students from 60 schools).

## 2.2 | Measures

### 2.2.1 | Outcome variable

Our outcome measure was *subjective IAQ*. This was measured by two items: "Have any of the following things bothered you at your school during this school year? a) Stuffy air (bad indoor air), b) unpleasant odor." These items were measured on a three-point scale (1 = not

at all, 2 = somewhat, 3 = a lot). A mean rating of the items was calculated. If the respondent had not answered both items, the score was not calculated (Cronbach's alpha = 0.71). The data source was the SHP.

### 2.2.2 | Mediator

*Reported symptoms* were measured by four items: "In the last six months, have you experienced any of the following symptoms, and how often?: a) Blocked or runny nose, b) Dry or sore throat, c) Cough, d) Dry or watery eyes." These items were measured on a four-point scale (1 = seldom or never, 2 = approximately once a month, 3 = approximately once a week, 4 = almost daily). A mean rating of the items was calculated. If the respondent had not answered all items, the score was not calculated (Cronbach's alpha = 0.79). The data source was the SHP. These symptoms have been shown in many studies to be related to poor IAQ.<sup>40,41</sup>

### 2.2.3 | A building-related predictor

*Observed dampness and mold* were measured by the following item: "Were the following issues evaluated in the most recent inspection of the health and safety of the school environment? Problems with dampness and mold." The response options were: no data available; not included in the inspection; inspected, no deficiencies detected; inspected, deficiencies detected but not yet corrected; inspected, deficiencies detected and corrected. In this study, we focus only on the third and fourth options, and they were recoded as follows: 0 = inspected, no deficiencies detected; 1 = inspected, deficiencies detected but not yet corrected. The data source was the BSHPCB.

### 2.2.4 | Background variables

*Gender, age, father's level of education, and student-perceived teacher-student relationships* were used as both student-level and school-level background variables. Father's level of education was used as an indicator of a student's socioeconomic status. The response options for *father's education* were: 1 = comprehensive school or equivalent (ie, primary level); 2 = upper-secondary school, high school, or vocational education institution (ie, secondary level); 3 = occupational studies in addition to upper-secondary school, high school, or vocational education institution (ie, secondary level and occupational studies); 4 = university, university of applied sciences, or other higher education institution (ie, tertiary level). The *perceived quality of teacher-student relationships* was measured by three items: "teachers encourage me to express my opinion in class"; "teachers are interested in how I am doing;" "teachers treat us (students) fairly." The response scale was 1 = fully agree, 2 = agree, 3 = disagree, 4 = fully disagree. A mean

rating of the items was calculated. Only if the respondent had answered all three items was the score calculated. Previous research has shown that the teacher-student relationship is related to subjective IAQ.<sup>17,42</sup> These items have also been used in many previous studies as indicators of teacher-student relationships.<sup>42,43</sup> The reliability was reasonable (Cronbach's alpha = 0.75). All these background variables were reported by the SHP.

The *school size* (ie, number of students) reported in the BSHPCB was used only as a school-level background variable.

### 2.3 | Statistical analyses

The mediation analysis was conducted by analyzing a two-level linear regression path model.<sup>44</sup> The model was built and then analyzed using Mplus statistical software version 8.0. Given that the data were hierarchical (schoolchildren nested within schools), multilevel analysis was required.<sup>45</sup> A full information maximum likelihood estimation (FIML) with robust standard errors (MLR estimator in Mplus) was used as an estimation method. MLR is robust to moderate violations of assumptions such as non-normality.<sup>46</sup>

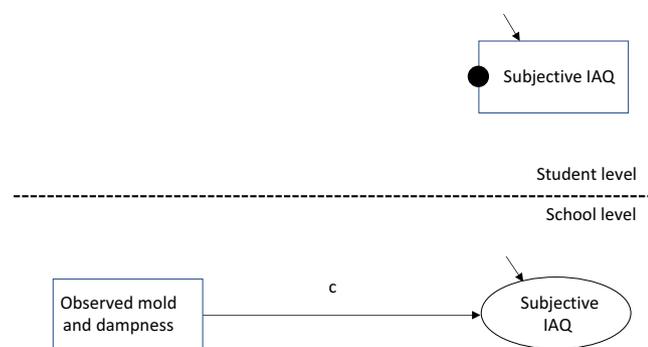
First, we analyzed a null model in which only the outcome variable was inserted into the model, without any predictors. The null model was used to estimate the variance between student and school levels and the intraclass correlation (ICC).<sup>45</sup> The ICC reported the proportion of variance that belonged to the school level. In addition, we tested whether other variables had significant variations at the school level, and we calculated their ICCs. Then we calculated the design effect of each variable. The design effect is a commonly used measure to estimate whether multilevel modeling is needed. When a researcher is interested in estimating the effects of group-level predictors, multilevel modeling is needed if the design effect is greater than 1.1.<sup>47</sup> The design effect is estimated as a function of the ICC and average cluster size.<sup>48</sup>

Second, the total effect between observed mold and dampness and subjective IAQ was estimated by a random intercept model<sup>49</sup>

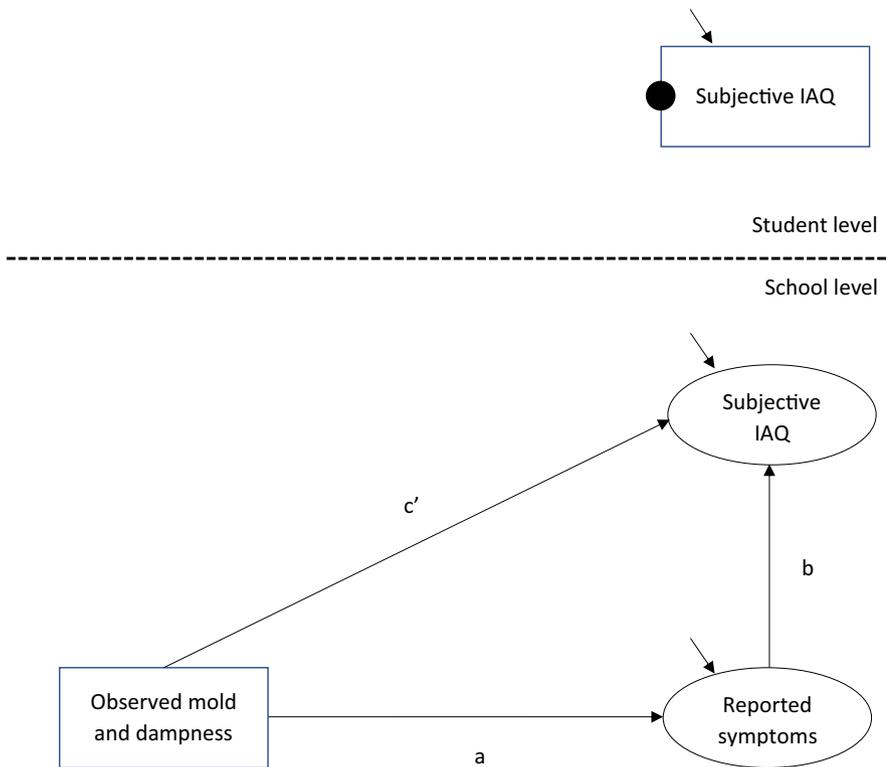
(see path c in Figure 2). First, we tested the unadjusted model (step 1). Then we adjusted the model with background variables in order to analyze the total effect of the final model (step 2), and finally we analyzed how the insertion of the mediator influenced this model (step 3). We used reported symptoms, the student-perceived quality of teacher-student relationships, father's education, age, and gender as both student-level and school-level covariates. This means that each of these covariates was decomposed into two latent uncorrelated components by Mplus. The first component represented the deviation of students' answers from their school mean (ie, student level). The second component represented the school mean (eg, the cluster mean of reported symptoms), and it reflected the deviation of each school mean from the grand mean (ie, school level).<sup>44,50</sup> School size and observed mold and dampness were included only at school level. All continuous predictors and background variables were centered by their grand means.

Finally, we estimated the direct and indirect effects. The *indirect effect* is the product of path *a* multiplied by path *b*, whereas the *direct effect* (*c'*) is the path between the predictor (ie, observed mold and dampness) and the outcome variable (ie, subjective IAQ) when the mediator (reported symptoms) is controlled for (see Figure 3). In our model, the independent variable and the mediator were at school level, and the outcome variable was at student level (a so-called 2-2-1 design).<sup>51</sup> If even one variable in the multilevel mediation model was a school-level variable, the *indirect effect* would exist only at the school level.<sup>52</sup> In the analysis, we followed a syntax based on articles by Preacher, Zyphur and Zhang<sup>52</sup> and Preacher, Zhang and Zyphur,<sup>53</sup> which are available online at <http://quantpsy.org/medn.htm> (accessed March 27, 2020). In addition, we counted the Monte Carlo confidence intervals (CI) to assess the significance of the indirect effects. These intervals accurately reflect the asymmetric nature of the sampling distribution of an indirect effect.<sup>53</sup> This analysis has been shown to be superior to the Sobel test.<sup>54</sup> We used the same background variables as when we estimated the total effect.

Both unstandardized and standardized estimates are reported. The unstandardized estimates are scaled so that if the predictor increases by one standard deviation, then the outcome variable increases by the standardized estimate. Standardization helps us to compare the effects of the estimates.  $R^2$  was used as an indicator of explained variance. Mplus makes it possible to count separate  $R^2$  for student and school levels.<sup>55</sup> Finally, when necessary, we report the effect size. The effect size is calculated as the unstandardized beta divided by the standard deviation of the outcome variable at the school level. This index is equivalent to Cohen's *d*.<sup>56</sup> Note that in one school the reported symptoms' z-score was  $>4$ . We analyzed its role by using Winsorization.<sup>57</sup> This allowed us to test how the potential outliers affected the results without reducing the sample size by transforming the extreme values of the distribution closer to the mean. The results remained almost the same and significant, so we decided to keep the data as it was.



**FIGURE 2** Statistical model of total effect between observed mold and dampness and subjective IAQ. The solid black circle corresponds to random intercept. The small arrows correspond to residual variance. Observed (measured) variables are represented by square boxes, and a latent (unmeasured) variable by ellipses



**FIGURE 3** The statistical model of direct and indirect effects between observed mold and dampness and subjective IAQ. The solid black circle corresponds to random intercept. The small arrows correspond to residual variance. Observed (measured) variables are represented by square boxes, and latent (unmeasured) variables by ellipses

**TABLE 1** Descriptive statistics for background variables, predictors, and outcome variable by indoor environment context

	Schools without dampness and mold (N = 162)			Schools with dampness and mold (N = 60)			P-value
	Mean or % (SD)	Min. - max.	N	Mean or % (SD)	Min. - max.	N	
Subjective IAQ	1.83 (0.62)	1-3	17 474	1.95 (0.62)	1-3	7312	<.001
Reported symptoms	1.65 (0.66)	1-4	17 026	1.68 (0.65)	1-4	7127	.002
Gender (female %)	51		8880	53		3850	.010
Age (years)	14.86 (0.72)	14-18	17 474	14.84 (0.72)	14-18	7312	.016
Father's education							
Primary level	9		1386	9		604	.272
Secondary level	34		5158	32		2108	
Secondary level and additional education	22		3419	22		1437	
Tertiary level	35		5387	36		2354	
Teacher-student relationship	2.27 (0.61)	1-4	17 105	2.28 (0.61)	1-4	7162	.375
School size (students per school)	398.41 (222.15)	62-1032	162	425.37 (206.78)	28-1013	60	.414

## 2.4 | Missing values

The numbers of missing values varied between the variables. Age, subjective IAQ, and observed mold and dampness had the lowest percentages of missing values (0%), and socioeconomic status had the highest (12%). Values were assumed to be missing at random.<sup>58</sup> In such cases FIML is a recommended method for handling missing data, because it uses all the available data for estimation and produces unbiased parameter estimators.<sup>59</sup>

## 3 | RESULTS

The descriptive statistics for the mediator, outcome, and background variables by observed mold and dampness context are reported in Table 1. Students reported significantly worse subjective IAQ and more symptoms in schools with observed mold and dampness than in schools without such problems. In addition, there was a small significant difference in the distribution of gender and age between these different schools. No other differences in background variables were detected.

First, the null models were analyzed.<sup>45</sup> There was a statistically significant variability in subjective IAQ within ( $\sigma^2_W = 0.347$ ,  $P < .001$ ) and between schools ( $\sigma^2_B = 0.045$ ,  $P < .001$ ). The ICC was 0.116, which means that 12% of the variability occurred between schools. The design effect was 13.8. This indicates that the sampling variance of the mean was almost 14 times larger than if the student sample was drawn using simple random sampling.<sup>47</sup> In addition, there was a statistically significant variability in reported symptoms within ( $\sigma^2_W = 0.428$ ,  $P < .001$ ) and between schools ( $\sigma^2_B = 0.005$ ,  $P = .001$ ). Although the ICC was very small at 0.012 (ie, 1.2%), the design effect was 2.3, which means that the sampling variance of the mean was more than two times larger than if the student sample was drawn using simple random sampling.<sup>47</sup> The design effect of the background variables used at both

student and school levels varied between 1.4 (gender) and 12.0 (father's education).

Table 2 reports the *student-level* and *school-level* correlations between predictors and outcome variables. All the correlations were significant. In order to visualize the high correlation between school-level reported symptoms and subjective IAQ, we present the relationship in Figure 4.

Next, a step-by-step random intercept model was analyzed in order to test the total effect between observed mold and dampness and subjective IAQ (see path c in Figure 2). In both the unadjusted model (step 1, Table 3) and the model adjusted by background variables (step 2, Table 3), the total effects between observed mold and dampness and subjective IAQ were significant (step 1: unstandardized beta = 0.173,  $P < .001$ ; step 2: unstandardized beta = 0.166,  $P < .001$ ). In the adjusted model, students reported 0.17 units worse subjective IAQ in schools with observed dampness and mold than in schools without. The effect size was 0.8, indicating a large effect.<sup>56</sup> The unadjusted model in step 1 explained 13% and the adjusted model in step 2 explained 24% of the between-school variance. However, after the reported symptoms were inserted into the model in step 3, the relationship between observed mold and dampness and subjective IAQ weakened, although it remained significant (unstandardized beta = 0.104,  $P = .002$ ). The adjusted relationship between reported symptoms and subjective IAQ is presented in Figure 5. The finding suggests a mediational model. This model explained 52% of the between-school variance.

Finally, we tested our mediational model (see Figure 3). There was a significant direct path (path c' in Figure 3): students reported worse IAQ in schools with dampness and mold than in schools without such problems (unstandardized beta = 0.104,  $P = .002$ , 95% CI = 0.039-0.169). In addition, there was a significant indirect path

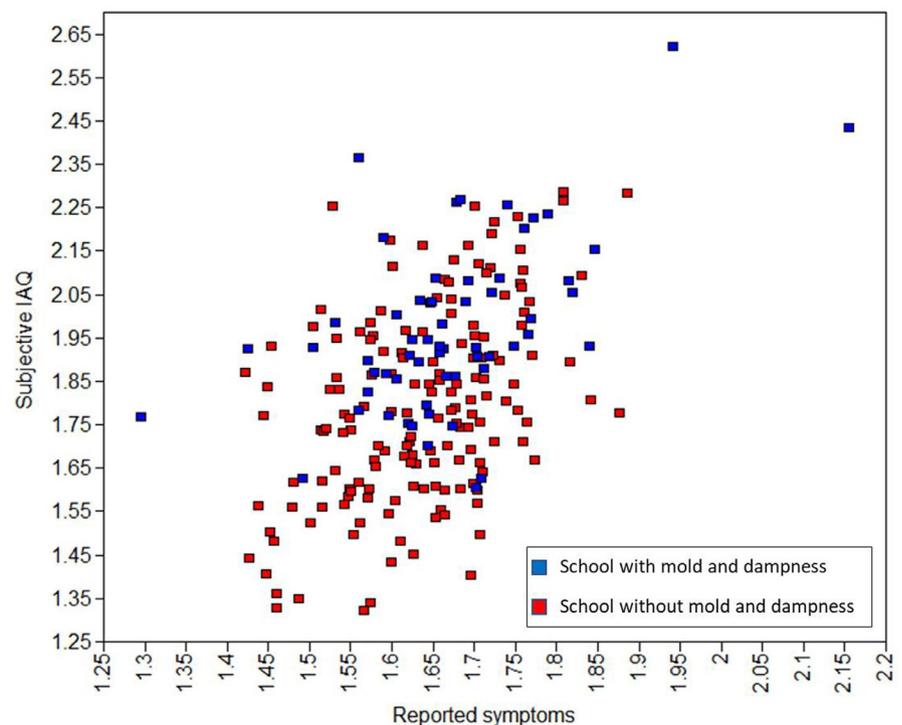
**TABLE 2** Pairwise correlation coefficients between main variables at student and school levels—correlations estimated using FIML with robust standard errors

	Student level (N = 24 786)		School level (N = 222)	
	1	2	1	2
1. Observed mold and dampness	—	—	1	
2. Reported symptoms	—	1	0.20*	1
3. Subjective IAQ	—	0.26***	0.36***	0.67***

\* $P < .05$ .

\*\* $P < .01$ .

\*\*\* $P < .001$ .



**FIGURE 4** The relationship between school-level reported symptoms and school-level subjective IAQ (N = 222 schools)

**TABLE 3** Parameter estimates for subjective indoor air quality as a function of individual-level and school-level variables (N = 24 786 students, N = 222 schools)

	Step 1			Step 2			Step 3		
	Unstand. Beta <sup>1</sup>	Stand. Beta <sup>2</sup>	Unstand. 95% CI	Unstand. Beta <sup>1</sup>	Stand. Beta <sup>2</sup>	Unstand. 95% CI	Unstand. Beta <sup>1</sup>	Stand. Beta <sup>2</sup>	Unstand. 95% CI
Intercept	1.80			1.27			1.52		
Student-level variables									
Reported symptoms <sup>a</sup>							0.19***	0.21***	0.18-0.20
Gender <sup>b</sup>				0.13***	0.11***	0.11-0.15	0.12***	0.10***	0.11-0.14
Age <sup>c</sup>				0.02***	0.03***	0.01-0.04	0.02**	0.02**	0.01-0.03
Father's education <sup>d</sup>				0.00	0.00	-0.01-0.01	0.00	0.00	-0.01-0.01
Teacher-student relationship <sup>e</sup>				0.28***	0.29***	0.27-0.30	0.24***	0.24***	0.23-0.26
R <sup>2</sup>				0.10			0.14		
School-level variables									
Observed mold and dampness <sup>f</sup>	0.17***	0.36***	0.11-0.23	0.17***	0.35***	0.10-0.23	0.10**	0.22**	0.04-0.17
Reported symptoms <sup>a</sup>							1.72***	0.60***	1.03-2.40
Gender <sup>b</sup>				0.36	0.06	-1.93-2.64	0.21	0.03	-1.38-1.79
Age <sup>c</sup>				0.12	0.07	-0.21-0.45	-0.09	-0.05	-0.42-0.24
Father's education <sup>d</sup>				0.11	0.18	-0.03-0.26	0.04	0.07	-0.08-0.17
Teacher-student relationship <sup>e</sup>				0.52***	0.29***	0.23-0.81	0.13	0.07	-0.20-0.46
School size <sup>g</sup>				0.00	0.00	-0.15-0.16	-0.05	-0.05	-0.19-0.09
R <sup>2</sup>	0.13			0.24			0.52		
$\sigma^2_W$	0.347***			0.314***			0.299***		
$\sigma^2_B$	0.040***			0.035***			0.022***		

<sup>1</sup>Unstandardized beta.<sup>2</sup>Standardized beta.<sup>a</sup>Scale 1-4, higher value indicates more frequently problems.<sup>b</sup>1 = male; 2 = female.<sup>c</sup>Years.<sup>d</sup>Scale 1-4, higher value indicates higher education.<sup>e</sup>Scale 1-4, higher value indicates more problems.<sup>f</sup>0 = no IA problems, 1 = IA problems.<sup>g</sup>Number of students. The original values are divided by 1000.\* $P < .05$ .\*\* $P < .01$ .\*\*\* $P < .001$ .

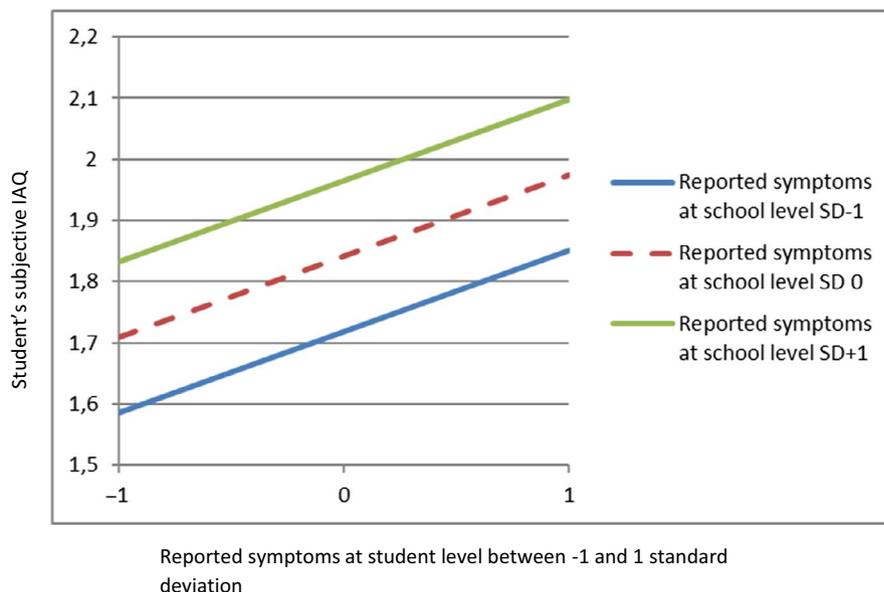
via reported symptoms (unstandardized beta = 0.062,  $P = .024$ , Monte Carlo 95% CI = 0.008-0.119). In schools with observed mold and dampness, students reported symptoms significantly more often than in schools without such problems (path *a* in Figure 3; unstandardized beta = 0.036,  $P = .023$ , 95% CI = 0.005-0.068). In addition, the higher the prevalence of symptoms at school level, the worse the students' subjective IAQ (path *b* in Figure 3; unstandardized beta = 1.716,  $P < .001$ , 95% CI = 1.031-2.400). This path explained 14% of the total effect of observed mold and dampness on subjective IAQ. In total, the model explained 52% of the between-school variance. The standardized regression coefficients are reported in Figure 6.

The model where no background variables were inserted showed a similar pattern (direct effect unstandardized beta = 0.106,  $P < .001$ , 95% CI = 0.050-0.162; indirect effect unstandardized beta = 0.067,  $P = .016$ , Monte Carlo 95% CI = 0.009-0.121). The model explained 50% of the school-level variance in subjective IAQ.

## 4 | DISCUSSION

We found that observed mold and dampness were related to students' subjective IAQ. This finding supported the research that has

**FIGURE 5** Students' subjective IAQ by student-level and school-level reported symptoms (see Table 3, step 3; student level N = 24 786, school level N = 222)



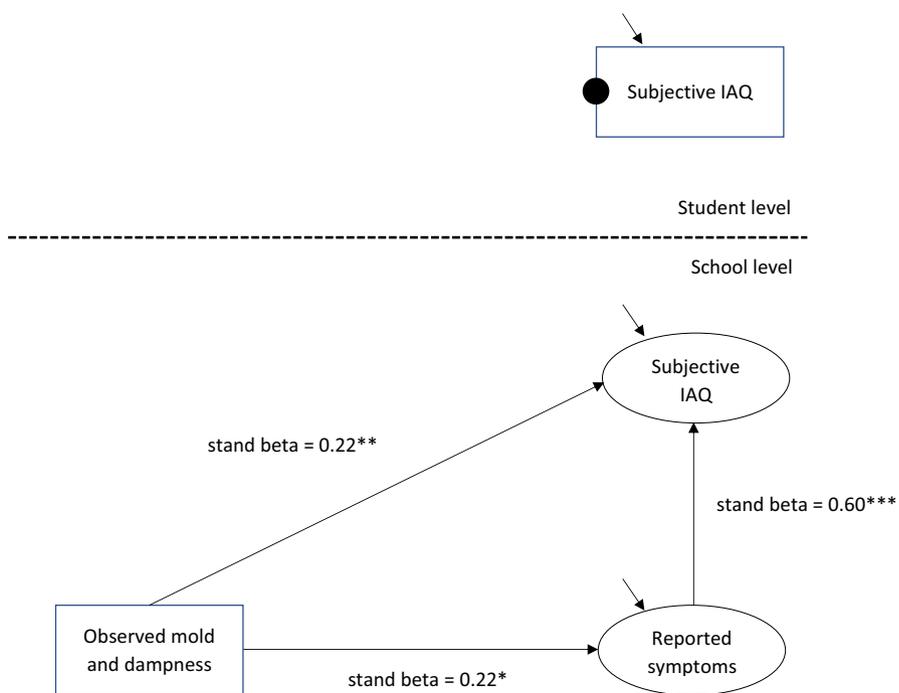
previously demonstrated that students' IAQ evaluations reflect IAQ evaluations derived from measurements and inspections.<sup>15,17</sup>

Our study further contributed this line of research by showing that the relationship between observed mold and dampness and students' subjective IAQ was partly mediated by the frequency of symptoms reported across students in a school: a) students reported more symptoms in schools with mold and dampness than without; b) the frequency of symptoms reported across students was related to their subjective IAQ; c) this indirect path was significant. Our results provided the first evidence that mold and dampness in a school building can influence subjective assessments of IAQ not only directly, but also via the students' overall frequency of symptoms: the relationship between school-level reported symptoms and subjective IAQ was high. Altogether, reported symptoms and observed

mold and dampness explained half of the school-level variance, which is a high percentage in a school survey.

This finding can be explained in many ways. As briefly reviewed in introduction, there is large individual variation in how aware people are of sensory stimuli and how sensitively they monitor them.<sup>20,26</sup> For example, while some people are highly aware of odors, others may only notice an odor after it has been brought to their attention by someone else.<sup>18,24</sup> It is thus possible that in schools where students have a lot of symptoms, other students who normally would not pay attention to the school's indoor environment (and would evaluate it as neutral if asked) might also become more aware of its quality. Another explanation might be that students use others' symptoms as an indicator of their school's IAQ. That is, they partly infer the quality of indoor air from others' symptoms. It is well known

**FIGURE 6** Standardized regression coefficients of the direct and indirect effects of the final model. The solid black circle corresponds to random intercept. The small arrows correspond to residual variance. Observed (measured) variables are represented by square boxes, and latent (unmeasured) variables by ellipses. N = 222. \* P < .05, \*\* P < .01, \*\*\* P < .001



that social factors affect how people interpret sensory stimuli<sup>32</sup> and people can infer the quality of indoor air from one's own symptoms.<sup>60</sup> This does not necessarily mean that their evaluations are wrong. It only indicates that they use different sources of information when making those evaluations.

Finally, this study demonstrated that subjective IAQ was significantly related to gender, teacher-student relationships, and students' age. As in the previous study by Finell and colleagues on a large Finnish student population, girls reported worse subjective IAQ at the student level than boys.<sup>17</sup> Similar findings have been reported among the adult population, although the findings have not been wholly consistent.<sup>61,62</sup> A large volume of literature has shown that women's olfactory ability is more sensitive than men's.<sup>21</sup> It is probable that women are also more likely to express their dissatisfaction with IAQ than men.<sup>61</sup> Furthermore, we replicated the finding that student-reported teacher-student relationships are related to subjective IAQ at both student and school levels.<sup>17</sup> However, this significant association disappeared at the school level when reported symptoms were included in the model. This is an interesting finding, and it suggests that there might be a complicated relationship between indoor environmental problems, reported symptoms, subjective IAQ, and teacher-student relationships. Although it is well known that psychosocial factors are related to IAQ perception, there is also evidence that indoor environmental problems may create psychosocial problems.<sup>63,64</sup> For example, previous research has shown that student-perceived student-teacher relationships are worse in schools with indoor environmental problems than in schools without such problems.<sup>39</sup> Therefore, it is likely that this relationship is bidirectional.

From the practical point of view, these results are especially important for authorities that utilize questionnaires to collect information about subjective IAQ in schools. Information about the IAQ problems experienced by a building's users often helps with the solution of potential IAQ problems. However, the assessment of the indoor air exposures in a building needs to be mainly based on other, more objective measurements. In addition, results regarding subjective IAQ should always be compared with suitable reference material, and if possible, schools should be tracked across time. If many schools are assessed at the same time, the hierarchical structure of the data needs to be taken into account in the analysis, for example by using multilevel methods. If the hierarchical structure of the data is not taken into account, there is a risk of spurious significant findings.<sup>45</sup>

The strengths of our study include the large and representative sample, which allows us to use sophisticated analytical methods: if one variable in a multilevel mediation model is a school-level variable, the indirect effect is tested at the school level. This requires a relatively large school-level sample. Our study also has limitations. The mediational model is inherently a process model, but both our mediator and outcome variables were derived from cross-sectional student data. Hence, our reasoning is strongly based on previous research and theories that support our model. Our findings can thus be considered preliminary, and longitudinal data are needed to confirm the findings. Another limitation is that our building-related

information is based on principals' reports of inspection results, we have only two relatively imprecise items measuring IAQ (stuffy air, unpleasant odor) and we do not have direct physical measurements.

To conclude, our analysis shows that using survey questionnaires to students about schools' IAQ might be a cost-effective way to evaluate the quality of school buildings' indoor air, in tandem with other measurements. However, authorities should be aware that students' evaluation of IAQ is a complex process, and students may use many sources of information when making such evaluations. If surveys on schools' IAQ are used, the possibility of an indirect effect needs to be considered.

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## CONFLICT OF INTEREST

There is no conflict of interest.

## AUTHOR CONTRIBUTION

**Eerika Finell:** Conceptualization (lead); Formal analysis (lead); Funding acquisition (lead); Methodology (equal); Visualization (lead); Writing-original draft (lead). **Asko Tolvanen:** Formal analysis (supporting); Methodology (equal); Writing-original draft (supporting). **Riikka Ikonen:** Investigation (lead); Writing-original draft (supporting). **Juha Pekkanen:** Writing-original draft (supporting). **Timo Ståhl:** Investigation (lead); Writing-original draft (supporting).

## ORCID

Eerika Finell  <https://orcid.org/0000-0002-9605-610X>  
 Asko Tolvanen  <https://orcid.org/0000-0001-6430-8897>  
 Riikka Ikonen  <https://orcid.org/0000-0003-1526-3463>  
 Juha Pekkanen  <https://orcid.org/0000-0002-1083-8777>  
 Timo Ståhl  <https://orcid.org/0000-0002-6677-4792>

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