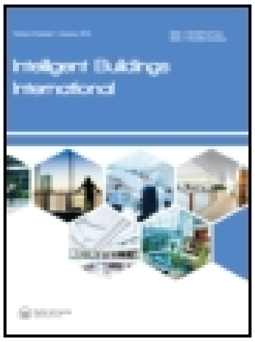

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ABSTRACT

To study the combined effect of different environmental factors on children in a classroom setting, 250 children from seven primary schools were exposed to 36 different environmental configurations ('all' and 'fewer' acoustical panels; 'displacement' and 'mixing' ventilation; sound type: 'children talk', 'traffic', and 'none'; and 'direct', 'indirect' and 'soft' lighting). In a four-way factorial design, they assessed with 18 groups on eight different days temperature, draught, noise, light and smell. Correlation, three-way ANOVA, comparison tests and multi-regression analysis were used to analyse relationships, and main, cross-modal and interaction effects. The results show that more acoustical panels had a positive effect on the children's assessment of sound. Sound type had a main effect on the assessment of sound. Statistical significant cross-modal effects were found for lighting and sound type on the assessment of smell. Significant three-way interactions between 'Vent', 'Sound', and 'Light' types were found for smell and light in the 'fewer panels' situations; and for light in the 'all panels' situations. Multiple-regression analysis also showed that perception of smell was significantly related with draught, sound and light perception in 'fewer panels' conditions. Further studies on these cross-modal interactions are recommended, specifically at individual level.

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Primary school children; lab study; combined effect; perceived indoor environmental qualities; different environmental configurations; perception

1. Introduction

From studies all over the world, it is clear that that the indoor environmental quality (IEQ) of classrooms can affect the wellbeing and learning performance of school children (e.g. Bluyssen 2017). Unfortunately, most of these studies were focused on single-dose response relationships of indoor air quality parameters, such as ventilation, certain emissions from indoor and outdoor sources and activities (e.g. Haverinen-Shaughnessy et al. 2012; Kim et al. 2005; Laiman et al. 2014; Madureira et al. 2015; Mendell et al. 2013; Simoni et al. 2010; Takaoka, Suzuki, and Nörback 2016; Toftum et al. 2015; WHO 2015; Bak-Biro et al. 2012). Studies on thermal (e.g. Dear de et al. 2015; Giuli de et al. 2015; Kwok and Chun 2003; Liang, Lin, and Hwang 2012; Wargocki and Wyon 2007), acoustical (e.g. Evans, Hygge, and Bullinger 1995; Hygge 2003; Montazami, Wilson, and Nicol 2012; Mydlarz et al. 2013) and lighting (e.g. Hathaway 1995; Heschong 2002; Park 2014; Winterbottom and Wilkins 2009; Yildirim, Cagatay, and Ayalp 2015) aspects have been limited compared to air quality aspects,

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as well as lab studies as compared to field studies. From the field studies performed, only few attempts have been made to perform a holistic analysis (e.g. Barett et al. 2013; Bluyssen, Zhang et al. et al. 2018).

And with regards to lab studies, studies on the combined effect of different environmental factors on people have been performed for mainly office settings. The effect of the thermal environment on smell, is probably the best documented. A clear relationship between temperature, humidity and perceived air quality (smell) has been shown (Toftum 2002; Fang et al. 2004). Conversely, not much evidence of an effect of air pollution on thermal assessment has been found (Torresin et al. 2018).

With respect to the effect of thermal environment on the perception of light (visual quality), several studies have been performed. For example, in a study with 20 subjects who evaluated the visual and thermal comfort at two temperatures and under three light source types (daylight, electric light and combined lighting), at a constant illuminance (300 lx) (Laurentin, Berrutto, and Fontoynont 2000). No effect of temperature on the perception of light was found, but it was found that light source type has an important influence on visual preference: the subjects preferred a lower illuminance under electric light than under daylight. In another lab study with 19 subjects, exposure to three scenarios (cold, comfortable and hot), the cold temperature scenario resulted in lower glare sensation votes (Garreton, Rodriguez, and Pattini 2016). Studies of the effect of lighting on thermal responses (see review by Te Kulve et al.2016) have shown that the colour and the intensity of light can affect thermal sensation, although the effect (cooler or warmer) differed per study. Interesting to note is that exposure to light might affect thermal regulation and also thermal comfort and sensation (Te Kulve et al. 2016).

Cross-modal effects of sound and odour perception (smell) have been shown by Velasco et al. (2014) in a study with 33 adults (including 20 females) that were exposed to six odours (three rated as unpleasant and three rated as pleasant) and no odour, while being exposed to three different sounds (with different pleasantness) and white noise (as a neutral stimulus). A significant effect on odour ratings was found when they listened to white noise: they rated the odours as less pleasant, as less sweet and drier than in the other auditory conditions.

Several studies have been performed showing that visual cues and olfaction are very strongly related. In a lab study performed by Jiang and Yang (Jiang and Yang 2011), an effect of illumination level on the perception of air quality was found: the higher the illumination level, the higher the acceptability of the air. Kemp and Gilbert (Kemp and Gilbert 1997) showed that odour intensity and colour lightness are correlated sensory dimensions. 38 subjects (20 men) matched colours to five odours presented at three concentrations and they rated odour intensity. Results suggest that stronger odours were associated with darker colours.

The effect of the acoustical environment on thermal perception has been studied by several researchers. Most of these studies have found that high levels of noise may lead to lower thermal comfort perception than in normal conditions (Pellerin and Candas 2003, 2004; Torresin et al. 2018). Witterseh, Wyon, and Clausen (2004) exposed 30 male subjects to combinations of three air temperatures and two acoustical conditions, while performing office work for 3 h under all six conditions. It was found that noise distraction and heat stress can sometimes counteract each other, as they both increase subjective distress and fatigue. In a lab study performed by Pan et al. (2003), in which nine healthy subjects were randomly exposed to noise, odour and their combination, it was concluded that additions of noise reduce (mask) the perception of discomfort from odour, and additions of odour have no or little effect on the perception of noise. The latter was also found by Balazova, Clausen, and Wyon (2007) in a study with 56 subjects, exposed to eight combinations of operative temperature (three), noise levels (two) and pollution loads (two).

With regards to the effect of lighting on sound perception, Nagano and Horikoshi (2014) found an effect of light level on sound perception, in a lab study with 47 females that were exposed to 20 combined conditions of four air temperatures, five noise levels at two different light levels (23 subjects to 3 lux and 24 subjects to 150 lux). The first group (exposed to 3 lux) perceived the environment as noisier than the second group (exposed to 150 lux). The combined effect of acoustical and visual distraction on cognitive performance and wellbeing in a semi-lab office environment was studied by Lieble et al. (2012) Visual distraction due to dynamic lighting caused significant complaints. Veitch (1990) studied the effects of illuminance and intermittent noise on reading comprehension, but found no interactions or main effects. In a study of three parameters, noise, heat and lighting, interactions between noise and heat and between noise and light on memory were found (Hygge and Knez 2001).

Although some trends have clearly been shown in all of those lab studies, the overall non-homogeneous results make it difficult to make strong conclusions. Moreover, lab studies on combined effects of (mostly two) environmental factors on human perception, usually considered the effect of a change in an environmental parameter, e.g. temperature, humidity, light intensity, sound level etc. The effect of different environmental configurations (e.g. different ventilation types, different lighting types, different sounds but the same sound level etc.) on the perception of sound, light, temperature and smell and the interaction effects among them is rarely considered. When it comes to children, it should be acknowledged that children might respond differently from adults, which indicates the need for lab studies with children.

In the field study (Bluyssen, Zhang, et al. 2018) of 54 classrooms of 21 primary schools in the Netherlands, performed in the spring of 2017, 1145 children filled out a questionnaire about their comfort and health. Among the 1145 children studied (average 10 years old), 87% was bothered by noise (mainly produced by themselves), 63% by smells (mainly produced by themselves), 42% by sunlight when shining, 35% didn't like the temperature in the classroom (too cold or too warm), 34% experienced temperature changes and only 7% was bothered by draught. Physical building characteristics of the classrooms studied were associated with the Classroom Symptom Index (location of school building, heating system, solar devices hampering opening windows or ventilation) and the Classroom Comfort Index (ventilation type, window frame colour, floor material and vacuum cleaning frequency). The field study showed first of all an urgent need for acoustical measures. Most classrooms have acoustical ceiling tiles, but this is not enough to create the acoustical environment the children need to feel well. With respect to air quality, it was evident that more attention should be paid to (local) source control and to different types of ventilation. And while the thermal environment showed interaction with both indoor air and outdoor (light) environment, indoor lighting (natural or artificial (led)) and colours of the interior and window frames seemed topics that need attention.

Therefore, as a follow-up, 335 children from the previous studied schools were invited to take part in a series of tests in a semi-laboratory environment (the SenseLab), to investigate preferences, needs and responses to single components (sound, thermal, light and air) and interactions of different environmental configurations more in depth. The SenseLab comprises of four test chambers (one for each IEQ factor: air, light, acoustics and thermal aspects) and the Experience room (a room for integral perception) (Bluyssen, van Zeist, et al. 2018). In the Experience room two studies were performed: an *exposure study*, to test the acceptability of light, sound, smell, temperature and draught with different environmental configurations; and a *workshop*, to identify current problems in the classroom (part 1) and to conceptualise design solutions by the children to solve these problems (part 2). In each of the test chambers, a test was performed that relates respectively to air (smell), thermal, lighting and acoustical quality (Armijos Moya, Zhang, and Bluyssen 2019; Bluyssen et al. 2019; Ortiz, Zhang, and Bluyssen 2019; Zhang, Tenpierik, and Bluyssen 2019). This paper reports the exposure study in the Experience room of the SenseLab in which children were exposed to different environmental configurations in order to study modal (main), cross-modal, interaction effects and relationships between indoor environmental factors.

2. Methods

2.1. Study design

This study was part of a series of tests performed in the SenseLab, with children from the previous studied schools (Bluyssen, Zhang, et al. 2018). From mid-February to the beginning of April in 2018, 335 children visited the SenseLab on 10 different days, located in the Science Centre (a technical and scientific museum at the premises of the TU Delft). The recruitment of children was on a voluntary basis. For the selection, the 21 schools visited in the spring of 2017 were approached directly.

A four-way factorial design was used to test the main, cross-modal and interaction effects of 36 different combinations of environmental conditions on the evaluation of temperature, noise, light and smell by the children:

- *With 'all' versus 'fewer' acoustical panels:* creating a different interior, a different view outdoors and creating a different acoustical quality – the RT (measured at four different points) in an empty room with all panels was 0.22 s and with fewer panels 0.70 s (optimal RT according to Fresh schools' guidelines (RVO.nl 2015) is lower than 0.4 s).
- *Two ventilation principles*: mixing and displacement ventilation with a ventilation rate of 600 m^3/h to provide 30–40 m^3/h per person and with a setting of 21 degrees Celsius. The air velocity (measured at four different points and three heights – 0.2, 1.2 and 1.6 m) in an empty room was below 0.03 m/s for both the displacement and mixing setting.
- *Three types (and patterns) of led-lighting*: direct, indirect and soft light (setting 100%). From luminance images taken (from the position of a child sitting in the last row, first column to the right from the centre aisle, looking straight towards the teacher's position), it was determined that soft light (40%) was the most comfortable lighting situation (by considering the luminance ratios only). Therefore, 40% soft light was taken as the basic setting. To compare the direct, indirect and soft led-light, 100% was used in order to minimise the effect of outdoor incoming lighting, which can differ a lot due to cloud forming.
- *Three types of background sound*: no sound, traffic and children talking, both at 60 dB(A) based on a review performed by Shield and Dockrell (2003) in which 45 dB(A) was found to be the 'normal background level and 60 dB(A) as the 'noise' background level.

Because it was not easy to move the acoustical panels in between groups or even days, it was decided to run the experiments first with 'all panels' (first 5 days) and then with 'fewer panels'. The panels were moved into the Experience room more than half year before the experiments, because the 'new' panels were odorous (emitting volatile organic compounds (VOCs)) and needed time to reduce their emissions. For both series, the order in which the 18 combinations were offered was randomised by a computer programme. Each group that participated was exposed to two of these combinations.

2.2. Facilities

During the SenseLab studies, the exposure study was performed in the Experience room of the SenseLab. The experience room is a room of circa 6.5 (l) × 4.2 (b) × 2.6 (h) m^3 gross for integrated perception of IEQ in a semi-lab environment, comprising of:

- A lighting system that comprises of different types and amount of lighting armatures (soft, direct and indirect light), that offers the possibility of individually dimming and controlling.
- A sound system that can produce different types of noise/sound within a range from 0 to 100 dB, and from 25 Hz to 20 kHz.
- Different types of ventilation: mixing, displacement and natural ventilation, able to provide a variable airflow with a range of 0–1200 m^3/h.
- Internal changeable materials: the floor and ceiling panels can be changed; walls can be added internally to the glass construction.

In the Experience room, a classroom set-up was created with 16 tables and chairs for the children, two chairs for the workshop leaders and a smart board (see Figure 1). The table tops comprised of light wood laminate, the floor was covered with grey smooth flooring material and the ceiling

Figure 1. Set-up in experience room (with acoustical panels and with soft light on).

comprised of white acoustical panels, as this combination was most common in the field study (Bluyssen, Zhang, et al. 2018).

2.3. General procedure

When the children arrived in the Science Centre, in the morning, they were led to a room where they could leave their bags and coats. They were given an introduction on why they were here and a short explanation about the schedule and the experiments. Then they were divided into two or three groups with a maximum of 16 children per group, depending on the total number of children. Each child received a pen (they could keep), a binder with a number on it (their personal number for the day) and the first page for the binder (for collecting personal information). They were asked to fill that in. Then each staff member was introduced and the different groups were brought to their first destination by the staff members. Per day, the research team comprised of 7–8 members.

In the case of schools with more than 32 children, three groups were formed: group 1 started in the experience room (maximum 16 children), group 2 in the test chambers (maximum four per test chamber) and group 3 in the Science Centre. After 35 min, group 1 went to the test chambers, group 2 to the Science Centre and group 3 to the Experience room. For the other days (schools with less than 32 children) two groups were formed: group 1 started in the Experience room and group 2 in the test chambers. After 35 min the groups switched. Both groups could visit the Science Centre when they finished both rounds.

2.4. Procedure experience room

The time-schedule for the Experience room per group was as follows:

- *Explanation* (3–5 min): Introduction of the tests in the Experience room with the smart board.
- *Evaluation 1* (3–5 min): The children were asked to fill in the one-page questionnaire (Appendix 1) and were told that it is important to evaluate the room in which they are now. If

they did not understand a question they could ask it. And when they were ready, they should put their pen down, so we could see they were ready.

- *Workshop part 1* (cc. 10 min)
- *Evaluation 2* (3–5 min): IEQ evaluation of combination 1 using the one-page questionnaire.
- *Workshop part 2* (cc. 10 min)
- *Evaluation 3* (3–5 min): IEQ evaluation of combination 2 using the one-page questionnaire.

The one-page questionnaire is presented in Appendix 1. The questions presented are based on the previous field study (Bluyssen, Zhang et al. 2018). The first round of questions was performed to get familiar with the procedure. During this round, the ventilation setting of the first combination to be tested was applied (mixing/displacement), no noise was added and the light exposure comprised of soft light with 40% intensity. The ventilation principle was changed (if changed) during the workshop part 2, because it took at least 3 min to change. Light and noise conditions were changed just before the evaluation of a combination to be tested. Basic setting for light was soft 40% (always during the workshop). Basic setting for noise was no noise added (always during the workshop). And the temperature setting during all experiments was 21°C.

2.5. Ethical aspects

After recruitment of the schools, the parents received an information letter and a consent letter from the school management, which usually happened two weeks before the visit. On the day of the visit, the research team received the consent forms from the teachers accompanying the children. For the children without permission to join the experiments, the school management generally decided not to have them join the visit. The Ethics committee of the TU Delft gave approval for the study.

2.6. Data management and analysis

All data from the questionnaires were manually typed in and stored in IBM SPSS Statistics 24.0. A second person systematically checked the input of the questionnaire data. Descriptive statistics such as mean and standard deviation (SD) values were used to summarise the data. Pearson, *t*-tests, three-way ANOVA, post-hoc comparison tests and multiple regression analysis, assuming a continuous scale and normal distribution, were used to analyse relationships, and modal (main), cross-modal and interaction effects. A modal effect is an effect of a variable on the perception of the same mode, for example, the effect of sound type on the assessment of sound. A cross-modal effect is an effect of a variable on the perception of another, for example, the effect of lighting type on the assessment of smell. A cross-modal interaction effect is the effect of for example the lighting type for different ventilation types on the assessment of smell.

3. Results

3.1. Participants

In total 250 children were included in the analysis of the assessment of 36 configurations on 8 different days divided into 18 groups of 11–16 children with 2 or 3 groups per day from six different schools (Table 1). The first (February 13) and the last day (April 5) were excluded from the analysis because after the first day the procedure in the Experience room was slightly adjusted, and at the last day of the experiments the panels had been brought back in the Experience room the day before, and it was noted that the panels emitted quit some odour and influenced the evaluations of the children. From the 250 children, 174 children were also involved in the earlier field study (Bluyssen, Zhang, et al. 2018). Their mean age was 10.5 years, 50% was girl, 90% felt good when filling in their personal information, four children were colour blind, 30 wore glasses or lenses and 39% claimed to have a cold.

Table 1. Personal information of the 250 children at the experimental days.

Date	Total children *n*	Girls *n* (%)	Mean age	Feel good *n* (%)	Allergy *n* (%)	Glasses/ lenses *n* (%)	Colour blind *n* (%)	Hearing problem *n* (%)	Having a cold *n* (%)
February 15	14	6 (43)	11.4	12 (86)	4 (29)	2 (14)	0	0	6 (43)
February 20	15	10 (67)	9.3	13 (87)	5 (33)	2 (13)	0	2 (13)	5 (36)
	11	5 (46)	9.4	11 (100)	10 (91)	1 (9)	0	0	1 (13)
February 22	12	5 (42)	10.1	9 (75)	2 (17)	1 (8)	0	0	6 (50)
	12	2 (17)	10	12 (100)	4 (33)	0	1 (8)	0	4 (33)
	12	9 (75)	10.3	12 (100)	4 (36)	1 (8)	0	0	8 (73)
March 8	15[a]	7 (47)	10.6	14 (93)	5 (33)	3 (20)	0	0	7 (47)
	15[a]	7 (47)	11.7	13 (93)	5 (33)	4 (27)	1 (7)	1 (7)	2 (13)
	14[a]	6 (43)	11.7	9 (64)	4 (29)	1 (7)	0	0	5 (36)
March 15	14	6 (43)	11.3	14 (100)	4 (29)	1 (7)	0	0	2 (14)
	12	8 (67)	11.1	10 (91)	4 (33)	2 (17)	1 (8)	1 (8)	5 (42)
March 20	14	11 (79)	10.3	13 (100)	5 (36)	2 (14)	1 (7)	0	11 (79)
	14	6 (43)	10.4	14 (100)	1 (7)	0	0	0	7 (50)
March 27	15	12 (80)	11.5	15 (100)	8 (53)	3 (20)	0	3 (20)	4 (27)
	15	5 (33)	11	14 (93)	2 (14)	2 (13)	0	0	7 (47)
April 3	16[b]	7 (44)	9.4	16 (100)	5 (31)	2 (13)	0	2 (13)	4 (25)
	16[b]	6 (38)	9.6	13 (81)	2 (13)	1 (6)	0	0	10 (63)
	14[b]	7 (50)	9.3	10 (71)	5 (39)	2 (14)	0	2 (14)	4 (29)
Total	250	125 (50)	10.5	224 (90)	69 (28)	30 (12)	4 (2)	1 (4)	98 (39)

[a]School from city in province North-Holland (North of the Netherlands).
[b]School from village in province Brabant (south of the Netherlands).

3.2. Descriptives

Figure 2 shows for each configuration (36 different combinations) the average ratings of assessed draught, smell, light, sound and temperature on a 5-rating bipolar scale. The 497 responses (237 from 'all panels' and 260 from 'fewer panels' conditions) of the children's mean perceived level of temperature, show for most of the configurations (31 out of 36), that children mostly felt between

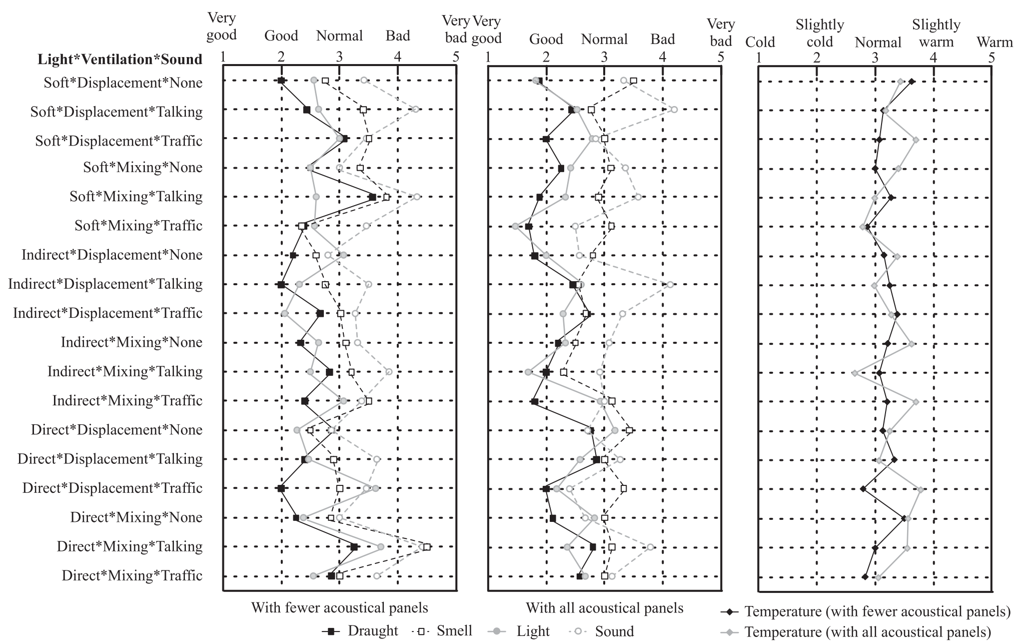

Figure 2. Graphical representation of mean ratings of perceived draught, smell, light, sound and temperature for 36 different configurations.

'normal' to 'slightly warm'. For perceived draught, smell and sound, two different questions were given to the children. The first question of each variable was introduced to identify whether they could sense them during the experiment. Then, the second questions were introduced to collect their self-rated quality of each variable. To investigate the perceived draught, smell, and sound in detail, only the responses to the first question of each variable that were not 'no', were included. As a result, 267 cases for perceived draught (137 from 'all panels' and 130 from 'fewer panels' conditions), 309 cases for perceived smell (146 from 'all panels' and 163 from 'fewer panels' conditions) and 431 cases (223 from 'all panels' and 208 from 'fewer panels' conditions) for perceived sound were collected. Lastly, 494 responses (237 from 'all panels' and 257 from 'fewer panels' conditions) were reported for perceived light. Compared to the perceived temperature, the difference between the mean assessed values between configurations for each of the assessment scales varied considerably (Figure 2).

3.3. Comparison analysis

To study possible relationships between the different assessments of the 36 configurations, the database with 500 assessments was divided into two: 240 assessments of 18 combinations with 'all panels' and 260 assessments of 18 combinations with 'fewer panels'. To compare a certain combination of ventilation type, lighting type and sound type with 'all' and with 'fewer' panels, a t-test was performed for each combination with 'all' panels and with 'fewer' panels (see Table 2). To identify main and cross-modal effects, a comparison analysis was performed using t-tests (for the comparison of ventilation types) and ANOVA (for the comparison of light types and sound types) (see Table 3).

3.4. Three-way ANOVA

To determine whether main and/or cross-modal interactions occurred, children's assessments were analysed with a three-way mixed randomised repeated ANOVA, with repeated measures on three factors, within each of the two panel conditions (see Table 4). The within factors were 'Vent' with the two levels 'displacement' and 'mixing', 'Sound' with the three levels 'children talk', 'traffic', and 'none', and 'Light' with the three levels 'direct', 'indirect' and 'soft'. Statistically significant interactions of 'Light*Vent*Sound' were found for the assessment of smell [$F(4,145) = 1.793$, $p = 0.048$] and Light [$F(4,240) = 3.265$, $p = 0.012$], when there were 'fewer panels', and for the assessment of light [$F(4,219) = 3.446$, $p = 0.009$] with the 'all panels' condition. For those significant interactions, differences between the levels of the within factors were examined by simple comparisons, holding the other two factors fixed. For the factors with three levels and with significant difference among them, pairwise comparisons were conducted to identify the difference between each two levels of them. Results are presented in Appendix 2.

3.5. Stepwise multi-regression analysis

A stepwise multiple regression analysis was applied to explore the inter-relationships between children's assessments of draught, smell, light and sound. The following three indicators were used to interpret the outcome:

- The statistical significance of the regression analysis, with $p < 0.05$ as a criterion.
- The percentage of variance explained (adj. R^2), using Cohen's guidelines for moderate (13%) and strong effects (26%) (Cohen 1988).
- The unstandardised regression coefficient (β), to compare the size of the effect of predictor variable on the dependent variable.

As shown in Figure 3(a), for the 'fewer panels' conditions, children's assessment of smell was strongly influenced (adj. $R^2 = 0.556$, $p < 0.001$) by the assessment of draught, sound and light.

Table 2. *T*-test of the same combination with 'all panels' and with 'fewer panels'.

			Children's assessment of				
Light type	Ventilation type	Sound type	Temperature mean (SD)	Draught mean (SD)	Smell mean (SD)	Light mean (SD)	Sound mean (SD)
Soft	Displacement	None	$p = 0.676$	$p = 0.796$	$p = 0.220$	$p = 0.072$	$p = 0.859$
– fewer panels 16			3.63 (0.81)	2 (0.41)	2.70 (0.67)	2.56 (1.03)	3.42 (1.16)
– all panels 11			3.45 (1.29)	1.88 (1.13)	3.50 (1.73)	1.82 (0.98)	3.33 (0.92)
Soft	Displacement	Talking	$p = 0.860$	$p = 0.973$	$p = 0.214$	$p = 0.821$	$p = 0.693$
– fewer panels 14			3.14 (0.66)	2.43 (0.98)	3.38 (1.06)	2.64 (1.39)	4.31 (0.63)
– all panels 15			3.20 (1.01)	2.44 (0.88)	2.78 (0.83)	2.53 (1.19)	4.20 (0.77)
Soft	Displacement	Traffic	$p = 0.136$	$p = 0.233$	$p = 0.383$	$p = 0.708$	$p = 0.106$
– fewer panels 14			3.07 (1.27)	3.00 (1.41)	3.50 (1.45)	3.00 (1.52)	3.46 (0.97)
– all panels 14			3.71 (0.91)	2.00 (0.82)	3.00 (0.76)	2.79 (1.48)	2.85 (0.90)
Soft	Mixing	None	$p = 0.399$	$p = 0.744$	$p = 0.642$	$p = 0.878$	$p = 0.454$
– fewer panels 12			3.00 (1.13)	2.50 (1.05)	3.33 (0.82)	2.50 (1.17)	3.00 (1.05)
– all panels 12			3.42 (1.24)	2.25 (1.58)	3.11 (0.93)	2.42 (1.44)	3.36 (1.12)
Soft	Mixing	Talking	$p = 0.479$	$\mathbf{p < 0.001}$	$p = 0.065$	$p = 0.573$	$\mathbf{p = 0.041}$
– fewer panels 15			3.27 (0.96)	3.56 (0.53)	3.78 (0.97)	2.60 (1.12)	4.33 (0.90)
– all panels 12			3.00 (0.95)	1.88 (0.64)	2.89 (0.93)	2.33 (1.30)	3.58 (0.90)
Soft	Mixing	Traffic	$p = 0.833$	$p = 0.061$	$p = 0.128$	$\mathbf{p = 0.006}$	$\mathbf{p = 0.033}$
– fewer panels 14			2.86 (0.77)	2.38 (0.52)	2.33 (0.87)	2.57 (1.09)	3.46 (0.97)
– all panels 15			2.80 (0.68)	1.70 (0.82)	3.11 (1.17)	1.47 (0.92)	2.50 (1.22)
Indirect	Displacement	None	$p = 0.195$	$p = 0.317$	$p = 0.558$	$\mathbf{p = 0.032}$	$p = 0.398$
– fewer panels 15			3.14 (0.53)	2.20 (0.45)	2.60 (0.52)	3.07 (1.58)	2.80 (0.42)
– all panels 15			3.40 (0.51)	1.80 (0.79)	2.80 (0.92)	2.00 (0.93)	2.57 (0.76)
Indirect	Displacement	Talking	$p = 0.390$	$p = 0.229$	$p = 0.540$	$p = 0.517$	$\mathbf{p = 0.041}$
– fewer panels 16			3.25 (1.00)	2.00 (0.77)	2.75 (0.75)	2.31 (1.20)	3.50 (0.52)
– all panels 15			3.00 (0.53)	2.45 (0.93)	2.55 (0.82)	2.60 (1.24)	4.13 (0.99)
Indirect	Displacement	Traffic	$p = 0.804$	$p = 1.000$	$p = 0.415$	$p = 0.495$	$p = 0.912$
– fewer panels 16			3.38 (1.02)	2.71 (0.76)	3.00 (0.71)	2.06 (1.00)	3.27 (0.65)
– all panels 14			3.29 (0.91)	2.71 (1.11)	2.67 (0.82)	2.29 (0.73)	3.42 (0.79)
Indirect	Mixing	None	$p = 0.305$	$p = 0.753$	$p = 0.131$	$p = 0.566$	$p = 0.342$
– fewer panels 14			3.21 (0.97)	2.33 (0.82)	3.09 (0.70)	2.64 (1.28)	3.31 (0.48)
– all panels 12			3.64 (1.03)	2.20 (0.45)	2.50 (0.93)	2.33 (1.44)	3.08 (0.67)
Indirect	Mixing	Talking	$p = 0.356$	$\mathbf{p = 0.013}$	$p = 0.070$	$p = 0.092$	$p = 0.086$
– fewer panels 14			3.07 (1.21)	3.00 (0.82)	3.20 (0.92)	2.50 (1.45)	3.85 (0.99)
– all panels 15			2.67 (1.11)	2.00 (0.82)	2.30 (1.16)	1.69 (0.85)	2.92 (1.56)
Indirect	Mixing	Traffic	$p = 0.207$	$p = 0.217$	$p = 0.360$	$p = 0.799$	$p = 0.264$
– fewer panels 14			3.21 (1.12)	2.40 (0.55)	3.50 (0.55)	3.07 (1.44)	3.38 (0.65)
– all panels 14			3.71 (0.91)	1.80 (0.84)	3.13 (0.83)	2.93 (1.49)	3.00 (1.04)
Direct	Displacement	None	$p = 0.670$	$p = 0.847$	$\mathbf{p = 0.022}$	$\mathbf{p = 0.045}$	$p = 0.753$
– fewer panels 15			3.13 (0.35)	2.86 (0.69)	2.50 (0.71)	2.27 (0.96)	3.17 (0.75)
– all panels 12			3.27 (1.19)	2.75 (1.28)	3.43 (0.79)	3.18 (1.25)	2.71 (0.49)
Direct	Displacement	Talking	$p = 0.365$	$p = 0.301$	$p = 0.715$	$p = 0.819$	$p = 0.302$
– fewer panels 15			3.33 (0.72)	2.40 (0.70)	2.89 (0.60)	2.47 (1.36)	3.64 (0.63)
– all panels 12			3.08 (0.67)	2.86 (1.07)	3.00 (0.58)	2.58 (1.24)	3.27 (1.10)
Direct	Displacement	Traffic	$\mathbf{p = 0.001}$	$p = 1.000$	$p = 0.569$	$\mathbf{p = 0.011}$	$\mathbf{p = 0.016}$
– fewer panels 14			2.79 (0.58)	2.00 (0.71)	3.00 (1.15)	3.62 (1.19)	3.46 (0.78)
– all panels 11			3.80 (0.79)	2.00 (0.89)	3.33 (1.12)	2.18 (1.33)	2.40 (1.17)

(*Continued*)

Table 2. Continued.

			Children's assessment of				
Light type	Ventilation type	Sound type	Temperature mean (SD)	Draught mean (SD)	Smell mean (SD)	Light mean (SD)	Sound mean (SD)
Direct	Mixing	None	$p = 0.800$	$p = 0.708$	$p = 0.743$	$p = 0.392$	$p = 0.451$
– fewer panels 16			3.50 (0.89)	2.25 (0.71)	2.86 (0.69)	2.38 (1.26)	3.00 (1.10)
– all panels 12			3.58 (0.79)	2.11 (0.78)	3.00 (0.93)	2.83 (1.53)	2.67 (0.98)
Direct	Mixing	Talking	$p = 0.138$	$p = 0.644$	$\mathbf{p < 0.001}$	$\mathbf{p = 0.005}$	$p = 0.101$
– fewer panels 14			3.00 (1.24)	3.25 (1.50)	4.50 (0.52)	3.71 (1.33)	4.42 (0.79)
– all panels 14			3.57 (0.65)	2.80 (1.30)	3.13 (0.83)	2.36 (1.01)	3.79 (1.05)
Direct	Mixing	Traffic	$p = 0.491$	$p = 0.580$	$p = 1.000$	$p = 0.805$	$p = 0.201$
– fewer panels 12			2.83 (1.03)	2.86 (1.07)	3.00 (1.10)	2.55 (1.44)	3.64 (1.12)
– all panels 15			3.07 (0.70)	2.57 (0.79)	3.00 (1.10)	2.67 (1.05)	3.13 (0.83)
Total			$p = 0.132$	$\mathbf{p = 0.004}$	$p = 0.080$	$\mathbf{p < 0.001}$	$\mathbf{p = 0.009}$
– fewer panels 260			3.17 (0.92)	2.56 (0.98)	3.12 (0.95)	3.55 (1.09)	2.68 (0.95)
– all panels 240			3.30 (0.93)	2.22 (0.90)	2.93 (0.99)	3.19 (0.92)	2.38 (0.95)

Note: *p*-values in bold mean statistically significant at 5% level.

Assessment of draught ($\beta = 0.45$) had a stronger influence than assessment of sound ($\beta = 0.293$) and light ($\beta = 0.22$). Children's assessment of smell also had a strong influence on the assessment of draught (adj. $R^2 = 0.430$, $p < 0.001$), sound (adj. $R^2 = 0.311$, $p < 0.001$) and light (adj. $R^2 = 0.267$, $p < 0.001$) (see Table 5). There was no statistically significant relationship found between assessment of draught, sound and light.

Under 'all panels' conditions (see Table 5), children's assessment of smell was moderately influenced (adj. $R^2 = 0.160$, $p < 0.001$) by assessment of draught and light. Assessment of draught ($\beta = 0.25$) had a slightly stronger influence than assessment of light ($\beta = 0.22$). Unlike 'fewer panels' conditions, draught, sound and light assessment were all inter-related to each other (see Figure 3(b)). Children's assessment of sound was moderated influenced (adj. $R^2 = 0.195$, $p < 0.001$) by draught ($\beta = 0.36$) and light assessment ($\beta = 0.19$). Draught was moderately influenced (adj. $R^2 = 0.199$, $p < 0.001$) by sound ($\beta = 0.35$) and smell ($\beta = 0.21$). Light was moderately associated (adj. $R^2 = 0.116$, $p < 0.001$) with sound ($\beta = 0.23$) and smell ($\beta = 0.22$).

4. Discussion

4.1. All vs. fewer acoustical panels

For perceived draught, light and sound quality, the configurations with 'fewer panels' were generally assessed worse than the same configurations with 'all panels' (see Table 2). For sound that was

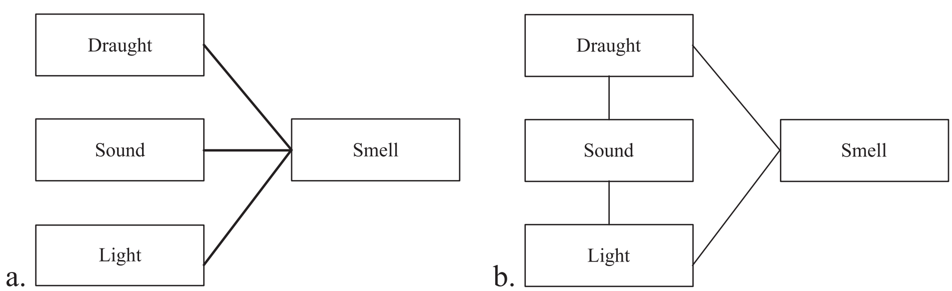

Figure 3. Inter-relationships between children's assessment of smell, draught, sound and light for (a) fewer and (b) all acoustical panels (thick solid lines indicate strong size of the effect (adj. $R^2 \geq 0.26$, $p < 0.05$) and solid lines indicate moderate size of the effect ($0.13 \leq$ adj. $R^2 < 0.26$, $p < 0.05$) (Cohen 1988)).

Table 3. Comparison analysis: for the 36 combinations, for the 18 'all panels' and the 18 'fewer panels' combinations.

	Children's assessment of				
	Temperature mean (SD)	Draught mean (SD)	Smell mean (SD)	Light mean (SD)	Sound mean (SD)
With all and with fewer panels ($N = 500$)					
Ventilation type: *n* (%)	$p = 0.274$	$p = 0.701$	$p = 0.096$	$p = 0.884$	$p = 0.814$
- Displacement 254 (50.8)	3.27 (0.86)	2.37 (0.94)	2.94 (0.91)	2.55 (1.25)	3.39 (0.96)
- Mixing 246 (49.2)	3.18 (0.99)	2.42 (0.97)	3.12 (1.01)	2.53 (1.31)	3.37 (1.08)
Lighting type: *n* (%)	$p = 0.962$	$p = 0.265$	$\mathbf{p = 0.015}$	$p = 0.088$	$p = 0.116$
- Soft 164 (32.8)	3.21 (0.99)	2.36 (1.04)	3.10 (1.05)	2.45 (1.25)	3.52 (1.09)
- Indirect 174 (34.8)	3.24 (0.94)	2.30 (0.85)	2.82 (0.84)	2.46 (1.27)	3.29 (0.93)
- Direct 162 (32.4)	3.24 (0.85)	2.53 (0.95)	3.19 (0.97)	2.72 (1.30)	3.32 (1.04)
Sound type: *n* (%)	$p = 0.068$	$p = 0.127$	$p = 0.270$	$p = 0.811$	$\mathbf{p < 0.001}$
- None 164 (32.4)	3.36 (0.90)	2.26 (0.94)	2.90 (0.85)	2.50 (1.26)	3.03 (0,89)
- Children talking 171 (34.2)	3.13 (0.92)	2.53 (0.97)	3.11 (1.01)	2.53 (1.27)	3.85 (0.99)
- Traffic 167 (33.4)	3.20 (0.95)	2.36 (0.94)	3.06 (1.02)	2.59 (1.31)	3.16 (0.98)
With all panels ($N = 240$)					
Ventilation type: *n* (%)	$p = 0.445$	$p = 0.183$	$p = 0.683$	$p = 0.483$	$p = 0.239$
- Displacement 119 (49.6)	3.34 (0.89)	2.33 (1.02)	2.96 (0.92)	2.44 (1.19)	3.29 (1.08)
- Mixing 121 (50.4)	3.25 (0.95)	2.10 (0.94)	2.89 (0.98)	2.33 (1.28)	3.11 (1.10)
Lighting type: *n* (%)	$p = 0.648$	$p = 0.064$	$\mathbf{p = 0.018}$	$p = 0.109$	$p = 0.375$
- Soft 79 (32.9)	3.25 (1.03)	2.02 (1.01)	3.02 (0.98)	2.23 (1.28)	3.32 (1.12)
- Indirect 85 (35.4)	3.26 (0.91)	2.17 (0.88)	2.64 (0.92)	2.31 (1.18)	3.20 (1.10)
- Direct 91 (31.7)	3.38 (0.82)	2.50 (1.02)	3.16 (0.88)	2.63 (1.23)	3.06 (1.06)
Sound type: *n* (%)	$\mathbf{p = 0.029}$	$p = 0.446$	$p = 0.189$	$p = 0.966$	$\mathbf{p < 0.001}$
- None 74 (30.8)	3.46 (0.99)	2.15 (1.07)	3.00 (0.99)	2.41 (1.31)	2.94 (0.89)
- Children talking 83 (34.6)	3.08 (0.87)	2.36 (0.94)	2.74 (0.89)	2.36 (1.15)	3.70 (1.14)
- Traffic 83 (34.6)	3.37 (0.88)	2.13 (0.92)	3.07 (0.95)	2.39 (1.26)	2.90 (1.03)
With fewer panels ($N = 260$)					
Ventilation type: *n* (%)	$p = 0.408$	$\mathbf{p = 0.034}$	$\mathbf{p = 0.005}$	$p = 0.606$	$p = 0.259$
- Displacement 135 (51.9)	3.22 (0.83)	2.42 (0.85)	2.92 (0.92)	2.64 (1.30)	3.49 (0.82)
- Mixing 125 (48.1)	3.12 (1.03)	2.75 (0.90)	3.34 (0.99)	2.73 (1.31)	3.63 (1.00)
Lighting type: *n* (%)	$p = 0.777$	$p = 0.371$	$p = 0.414$	$p = 0.535$	$p = 0.079$
- Soft 85 (32.7)	3.18 (0.95)	2.72 (0.96)	3.17 (1.11)	2.65 (1.20)	3.71 (1.04)
- Indirect 89 (34.2)	3.22 (0.98)	2.45 (0.79)	2.98 (0.74)	2.60 (1.35)	3.38 (0.70)
- Direct 86 (33.1)	3.12 (0.86)	2.56 (0.90)	3.22 (1.05)	2.81 (1.36)	3.60 (0.95)
Sound type: *n* (%)	$p = 0.207$	$p = 0.260$	$\mathbf{p = 0.002}$	$p = 0.532$	$\mathbf{p < 0.001}$
- None 88 (33.8)	3.29 (0.82)	2.39 (0.72)	2.81 (0.70)	2.57 (1.22)	3.13 (0.88)
- Children talking 88 (33.8)	3.18 (0.97)	2.71 (0.97)	3.43 (1.00)	2.69 (1.35)	4.00 (0.82)
- Traffic 84 (32.3)	3.04 (0.99)	2.59 (0.91)	3.06 (1.09)	2.79 (1.34)	3.45 (0.85)

Notes: *p*-values obtained from t-tests (for the comparison of ventilation types) and ANOVA (for the comparison of light types and sound types); *p*-values in bold mean statistically significant at the 5% level.

Table 4. *P*-values of the three-way interactions 'Light*Vent*Sound' assessed with three-way ANOVA.

Assessment	'All panels'	'Fewer panels'
Temp	0.057	0.334
Draught	0.147	0.093
Smell	0.821	**0.048**
Light	**0.009**	**0.012**
Sound	0.087	0.530

Note: *p*-values in bold mean statistically significant at 5% level.

expected (14 out of 18 with 4 statistically significant differences), since the RT for the 'all panels' situation was below the recommended maximum level for Class A schools of 0.4 s (RVO.nl 2015). Sound was assessed worse for the 'fewer panels' situation and the combination 'soft light – mixing vent – talking sound' [$t(25) = 2.152$, $p = 0.041$]; 'soft light – mixing vent – traffic sound' [$t(25) = 2.252$, $p = 0.033$]; and 'direct light – displacement vent – traffic sound' [$t(21) = 2.61$, $p = 0.016$]. Additionally, the assessment was worse for the 'all panels' situation and the combination 'indirect light – displacement vent – talking sound' [$t(27) = 2.213$, $p = 0.041$].

Table 5. Multiple regression analysis of children's evaluations of indoor environmental qualities for 'fewer' and 'all' acoustical panel combinations.

Dependent variables	Predictor variables	B	SE	β	*t*	*p*	VIF
	'Fewer panels'						
Smell	(constant)	0.29	0.29		1.02	0.309	
	Draught	0.45	0.08	0.45	5.74	<0.001	1.321
	Noise	0.31	0.08	0.29	3.75	<0.001	1.293
	Light	0.18	0.06	0.22	2.95	0.004	1.188
	R^2(adj. R^2) = 0.570 (0.556) F = 40.233 p < 0.001 Durbin-Watson = 1.903						
Sound	(constant)	1.87	0.27		6.89	<0.001	
	Smell	0.54	0.08	0.56	6.59	<0.001	1
	R^2(adj. R^2) = 0.319 (0.311) F = 43.470 p < 0.001 Durbin-Watson = 1.912						
Draught	(constant)	0.69	0.26		2.66	0.009	
	Smell	0.67	0.08	0.66	8.49	<0.001	1
	R^2(adj. R^2) = 0.436 (0.430) F = 72.024 p < 0.001 Durbin-Watson = 2.197						
Light	(constant)	0.98	0.37		2.65	0.01	
	Smell	0.58	0.11	0.48	5.21	<0.001	1
	R^2(adj. R^2) = 0.286 (0.267) F = 27.096 p < 0.001 Durbin-Watson = 1.896						
	'All panels'						
Smell	(constant)	1.70	0.25		6.71	<0.001	
	Draught	0.26	0.09	0.25	5.12	<0.001	1.083
	Light	0.19	0.08	0.22	3.56	<0.001	1.083
	R^2(adj. R^2) = 0.183 (0.160) F = 8.190 p < 0.001 Durbin-Watson = 1.882						
Sound	(constant)	1.87	0.27		6.89	<0.001	
	Draught	0.42	0.10	0.36	4.15	<0.001	1.083
	Light	0.19	0.09	0.19	2.20	0.03	1.083
	R^2(adj. R^2) = 0.209 (0.195) F = 14.658 p < 0.001 Durbin-Watson = 1.440						
Draught	(constant)	0.75	0.29		2.56	0.012	
	Noise	0.30	0.08	0.35	4.01	<0.001	1.104
	Smell	0.20	0.09	0.21	2.34	0.021	1.104
	R^2(adj. R^2) = 0.213 (0.199) F = 72.024 p < 0.001 Durbin-Watson = 2.130						
Light	(constant)	0.98	0.37		2.65	0.01	
	Noise	0.23	0.09	0.23	2.43	0.017	1.104
	Smell	0.26	0.11	0.22	2.41	0.018	1.104
	R^2(adj. R^2) = 0.152 (0.136) F = 8.422 p < 0.001 Durbin-Watson = 1.116						

For light, the changing outdoor sky and incoming light (cloud forming) most likely had less influence on the lighting quality with the 'all panels' situation, which could explain the finding that in 12 combinations (of which four significant different), the lighting was assessed worse in the situation with 'fewer panels'. Light was assessed statistically significant worse in the 'fewer panels' condition for the combination of 'soft light – mixing vent – traffic sound' [$t(51) = 2.852$, $p = 0.006$]; 'indirect light – displacement vent – no sound' [$t(28) = 2.256$, $p = 0.032$]; 'direct light – displacement vent – traffic sound' [$t(22) = 2.786$, $p = 0.011$]; and 'direct light – mixing vent – talking sound' [$t(26) = 3.048$, $p = 0.005$]. In the 'all panels' situation it was assessed statistically significant worse for the combination of 'direct light – displacement vent – talking sound' [$t(24) = 2.113$, $p = 0.045$].

For ten combinations smell was assessed worse in the 'fewer panels' conditions, but only two combinations showed a statistical significant difference between the 'fewer panels' and 'all panels' condition: the combination 'direct light – mixing vent – talking sound' [$t(18) = 4.554$, $p < 0.001$] for which the 'fewer panels' situation was assessed worse; and the combination 'direct light – displacement vent – no sound' [$t(21) = 2.546$, $p = 0.022$], which was assessed worse in the 'all panels' condition. These findings could indicate that the panels were not the most important pollution source present.

For 14 combinations draught was assessed worse for the 'fewer panels' situations, of which only two were found statistical significant different: for the combinations 'soft light – mixing vent – talking sound' [$t(19) = 5.943$, $p < 0.001$] and for 'indirect light – mixing vent – talking sound' [$t(21) = 2.352$, $p = 0.013$]. It could be that the glass surface, which was more exposed in the 'fewer panels' situation, had a lower radiant temperature than the panel surface, which could have caused a feeling of draught. Unfortunately, radiant temperatures were not measured; only the air temperature, so this cannot be confirmed.

For perceived temperature, small variations were found between 'all panels' and 'fewer panels' conditions. The only significant difference was found for the combination 'direct light – displacement vent – traffic sound' [$t(22) = 3.641$, $p = 0.001$], in which the 'all panels' situation was assessed slightly warmer.

4.2. (Cross) modal effects

In Table 3, the outcome of the comparison analysis in order to identify the modal and cross-modal effects of the different combinations on the assessments is presented.

'Sound type' clearly had a main effect on assessment of 'sound'. For 'all the configurations' tested (including 'all panels' and 'fewer panels' situations) and the 'fewer panels' situation, sound was assessed the worst for children talking and the best for no sound [$F(2,216) = 20.594$, $p < 0.001$]. For the 'all panels' situation, sound was assessed the worst for children talking and the best for traffic sound [$F(2,439) = 32.107$, $p < 0.001$]. In the 'all panels' situation, sound was assessed better than in the 'fewer panels' situation, no matter what sound type [$F(2,220) = 14.979$, $p < 0.001$].

'Sound type' additionally showed a significant cross-modal effect on 'temperature' assessment for the 'all panels' situation: temperature was assessed the coldest for no sound and neutral for children talking [$F(2,234) = 3.604$, $p = 0.029$]. This could indicate a counteraction or masking effect, found before by several researchers (Pan et al. 2003; Witterseh, Wyon, and Clausen 2004). Also, a significant cross-modal effect on 'smell' assessment was found for the 'fewer panels' situation: smell was assessed the worst for children talking and the best for no sound [$F(2,160) = 6.26$, $p = 0.002$].

An interesting finding is the effect of children talking on both the assessment of smell and the assessment of sound. In the field studies (Bluyssen, Zhang, et al. 2018), it was found that 87% of the children was bothered by noise and 63% by smell, both created by themselves. Among the 174 children from the field study that joined the current lab study, 118 (67.8%) were bothered by smell and 153 (87.9%) were bothered by noise. In this lab study among the 174 children (348 cases: they each assessed two combinations), 67 (19.2%) cases were bothered by smell, and 152 (43.7%) cases were bothered by noise. Correlation analysis (Chi-square test) showed a significant relationship between noise and smell assessment in both the field study ($p = 0.048$) and this lab study ($p = 0.000$). These relationships could indicate that some kind of conditioning has taken place: hearing of children talking triggers the mind of children to be bothered by sound and smell.

'Lighting type' showed a significant cross-modal effect on the assessment of 'smell' for all the combinations tested [$F(2,306) = 4.266$, $p = 0.015$] as well as for the 'all panels' situation [$F(2,143) = 4.12$, $p = 0.018$]: smell was assessed the worst for direct light and the best for indirect light. According to a previous study (Jiang and Yang 2011) with adults in which perceived air quality was found to be related to the illuminance level, this is most likely due to cross-modal effects between visual and olfactory cues.

'Ventilation type' showed a significant main effect on the assessment of 'draught' [$t(129) = 2.131$, $p = 0.034$] and 'smell' [$t(161) = 2.831$, $p = 0.005$], for the 'fewer panels' situation: draught was assessed the worst for mixing and the best for displacement ventilation; smell was assessed the worst for mixing and the best for displacement ventilation. Displacement ventilation as applied in the Experience room, is meant to remove all pollutants emitted and expired by the children through the upward movement of the air, while with mixing ventilation the air pollution is mixed and not immediately removed. Also, in the 'fewer panels' situation, the major pollution sources present were the children, while in the 'all panels' situation the panels themselves could have emitted some VOCs as well.

4.3. Three-way interactions

Significant three-way interactions between 'Vent', 'Sound', and 'Light' were found for children's smell assessment in the 'fewer panels' conditions [$F(4,145) = 1.793$, $p = 0.048$] (Figure 4); for

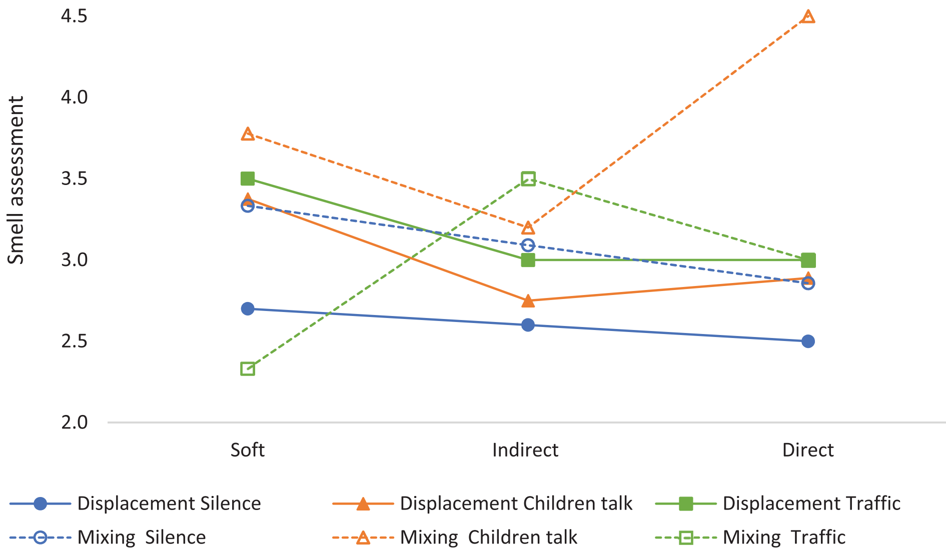

Figure 4. Means of smell assessments for the 'fewer' acoustical panels conditions.

children's light assessment in the 'fewer panels' conditions [$F(4{,}240) = 3.265$, $p = 0.012$] (Figure 5) and for children's light assessment in the 'all panels' conditions [$F(4{,}219) = 3.447$, $p = 0.009$] (Figure 6). For each of these three-way interactions, the simple comparisons (Appendix 2) resulted in several significant differences.

Several interactions seem to affect the assessment of smell in the 'fewer panels' situation, and the assessment of 'light' in the 'fewer' and in the 'all panels' situation. Research has shown that most of the cross-modal integration between sensory cues or stressors (e.g. olfactory, visual, auditory, gustatory, tactile, trigeminal cues) seems to occur at the level of the central nervous system (Seo and Hummel 2017). So, when a person is exposed to different sensory stressors at the same time, it is not strange

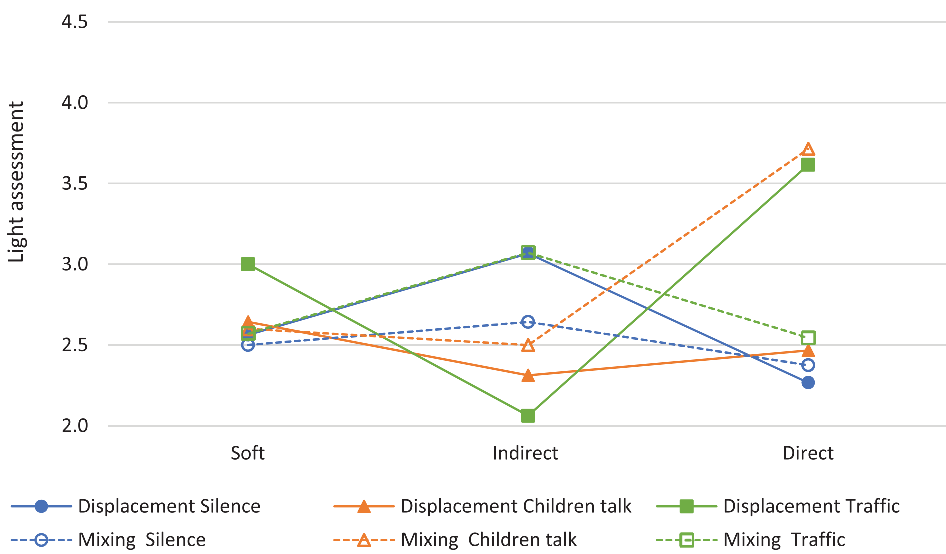

Figure 5. Means of light assessments for the 'fewer' acoustical panels conditions.

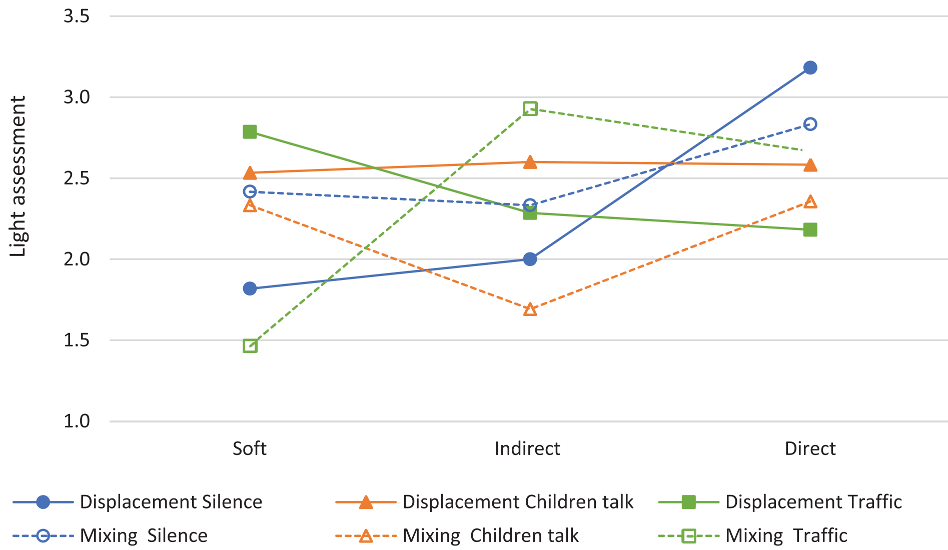

Figure 6. Means of light assessments for the 'all' acoustical panels conditions.

that assessments of these different stressors are affected by each other. Additionally, this effect is most likely influenced by personal sensitivities, previous exposures, expectations and preferences.

4.4. Inter-relationships of children's assessment of smell, draught, sound and light

The results of the multi-regression analysis suggest, first, that under 'all panels' conditions, perceived smell was less related to the other assessments than under 'fewer panels' conditions. In the latter strong associations were demonstrated with the other assessments. This supports the finding of the three-way interaction effect on children's' assessment of smell under 'fewer panels' conditions. Second, it appears that children's' evaluation of smell is either directly or indirectly associated with the assessments, regardless the presence of acoustical panels except for the assessment of temperature where no association was reported. Lastly, the results have shown significant differences between the inter-relationships of children's' evaluations of indoor environmental quality derived from 'fewer panels' to those obtained from 'all panels'. It suggests a clear influence of having 'fewer panels' on children's assessment of smell, sound, draught and light.

4.5. Strengths and limitations

As many conditions as possible were created to explore combined effects in a real-life classroom. Each group of on average 14 children was exposed to two combinations of the in total 36 configurations tested. The Experience room was used as a classroom, in which maximum 16 children could join the tests that were performed. In the field, most classrooms can have at least 30 children.

To make it a true randomised design including the panel situation ('all panels' or 'fewer panels'), the tests performed with all the panels should not have been performed first and then the tests with 'fewer panels'. Additionally, in a true randomised design each group of children should have been exposed to only one configuration and not two. But for practical reasons, the procedure was performed as described.

Another limitation of the study is the assumption that all groups would assess in the same way, not being confounded by their personal differences in experiences, preferences or needs. In the field study (Bluyssen, Zhang, et al. 2018), it was concluded that children do have different annoyances and different preferences related to the IEQ in classrooms (Zhang, Ortiz, and Bluyssen 2019).

5. Conclusions

This study was a first attempt to study main, cross-modal and interaction effects of different environmental configurations (different ventilation type, sound type and lighting type for two different amounts of acoustical panels) in the Experience room of the SenseLab on the assessment of sound, light, smell, draught and temperature by primary school children.

The results show that more acoustical panels had a positive effect on the children's assessment of sound. Additionally, a clear influence of 'fewer' acoustical panels on children's' evaluation of smell, draught and light was found. Furthermore, sound type, especially 'children talking' affected the assessment of both sound and smell, indicating that children are perhaps pre-conditioned in their response by hearing children talk. Smell was, in general, assessed the worst with sound type 'children talking', ventilation type 'mixing' and light type 'direct light', while no smell was added.

In future studies, it seems worth to study these possible cross-modal interactions further at individual level, e.g. exposing each individual to each of the configurations to be tested, in order to minimise the effect of personal differences in preferences and needs.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Armijos Moya, T., D. Zhang, and P. M. Bluyssen. 2019. "Perceived Air Quality of Different Sources of Smell Evaluated by Primary School Children." Proceedings CLIMA 2019, Bucharest.

Bak-Biro, Z., D. J. Clements-Croome, N. Kochhar, H. B. Awbi, and M. J. Williams. 2012. "Ventilation Rates in Schools and Pupils Performance." *Building and Environment* 48: 215–223.

Balazova, I., G. Clausen, and D. P. Wyon. 2007. "The Influence of Exposure to Multiple Indoor Environmental Parameters on Human Perception, Performance and Motivation." Proceedings of CLIMA 2007, Helsinki.

Barett, P., Y. Zhang, J. Moffat, and K. Kobbacy. 2013. "A Holistic, Multi-level Analysis Identifying the Impact of Classroom Design on Pupils' Learning." *Building and Environment* 59: 678–689.

Bluyssen, P. M. 2017. "Health, Comfort and Performance of Children in Classrooms – New Directions for Research." *Indoor and Built Environment* 26: 1040–1050.

Bluyssen, P. M., F. van Zeist, S. Kurvers, M. Tenpierik, S. Pont, B. Wolters, L. van Hulst, and D. Meertins. 2018. "The Creation of Senselab: A Laboratory for Testing and Experiencing Single and Combinations of Indoor Environmental Conditions." *Intelligent Buildings International* 10: 5–18.

Bluyssen, P. M., D. Zhang, A.-J. Krooneman, and A. Freeke. 2019. "The Effect of Wall and Floor Colouring on Perceived Thermal Comfort and Draught Feeling of Primary School Children." Proceedings CLIMA 2019, Bucharest.

Bluyssen, P. M., D. Zhang, S. Kurvers, M. Overtoom, and M. Ortiz-Sanchez. 2018. "Self-reported Health and Comfort of School Children in 54 Classrooms of 21 Dutch School Buildings." *Building and Environment* 138: 106–123.

Cohen, J. 1988. *Statistical Power Analysis for the Behavioural Sciences*. 2nd ed. Hillsdale, NJ: Erlbaum.

Dear de, R., J. Kim, C. Candido, and M. Deuble. 2015. "Adaptive Thermal Comfort in Australian School Classrooms." *Building Research & Information* 43: 383–398.

Evans, G. W., S. Hygge, and M. Bullinger. 1995. "Chronic Noise and Psychological Stress." *Psychological Science* 6: 333–338.

Fang, L., D. P. Wyon, G. Clausen, and P. O. Fanger. 2004. "Impact of Indoor Air Temperature and Humidity in an Office on Perceived Air Quality, SBS Symptoms and Performance." *Indoor Air* 14: 74–81.

Garreton, J. Y., R. Rodriguez, and A. Pattini. 2016. "Effects of Perceived Indoor Temperature on Daylight Glare Perception." *Building Research & Information* 44: 907–919.

Giuli de, V., R. Zecchin, L. Corain, and L. Salmasso. 2015. "Measurements of Indoor Environmental Conditions in Italian Classrooms and Their Impact on Children's Comfort." *Indoor and Built Environment* 24: 689–712.

Hathaway, W. E. 1995. "Effects of School Lighting on Physical Development and School Performance." *The Journal of Educational Research* 88: 228–242.

Haverinen-Shaughnessy, U., A. Borras, M. Turunen, J. P. Zock, L. Casas, R. Shaughnessy, M. Taubel, et al. 2012. "HITEA Study Group Occurrence of Moisture Problems in Schools in Three Countries from Different Climatic Regions of Europe Based on Questionnaires and Buildings Inspections – the HITEA Study." *Indoor Air* 22: 457–466.

Heschong, L. 2002. "Day Lighting and Student Performance." *ASHRAE Journal* 44: 65–67.

Hygge, S. 2003. "Classroom Experiments on the Effects of Different Noise Sources and Sound Levels on Long-Term Recall and Recognition in Children." *Applied Cognitive Psychology* 17: 895–914.

Hygge, S., and I. Knez. 2001. "Effects of Noise, Heat and Indoor Lighting on Cognitive Performance and Self-reported Affect." *Journal of Environmental Psychology* 21: 291–299.

Jiang, J. T., and C. Z. Yang. 2011. "Investigation of the Subjective Evaluation of Indoor Illumination Level on Perceived Air Quality." *7th International Symposium on Heating, Ventilating and Air Conditioning, Proceedings of ISHVAC 2011*, Vol. 2, 453–458.

Kemp, S. E., and A. N. Gilbert. 1997. "Odor Intensity and Color Lightness are Correlated Sensory Dimensions." *The American Journal of Psychology* 110: 35–46.

Kim, J. L. E., L. Mi, Y. Johansson, M. Smedje, and G. Nörback. 2005. "Current Asthma and Respiratory Symptoms Among Pupils in Relation to Dietary Factors and Allergens in the School Environment." *Indoor Air* 15: 170–182.

Kwok, A. G., and C. Chun. 2003. "Thermal Comfort in Japanese Schools." *Solar Energy* 74: 245–252.

Laiman, R., C. He, M. Mazaherri, S. Clifford, F. Salimi, L. R. Crilley, M. A. M. Mokhtar, and L. Morawska. 2014. "Characteristics of Ultrafine Particle Sources and Deposition Rates in Primary School Classrooms." *Atmospheric Environment* 94: 28–35.

Laurentin, C., V. Berrutto, and M. Fontoynont. 2000. "Effect of Thermal Conditions and Light Source Type on Visual Comfort Appraisal." *Lighting Research and Technology* 32: 223–233.

Liang, H. H., T. P. Lin, and R. L. Hwang. 2012. "Linking Occupants' Thermal Perception and Building Thermal Performance in Naturally Ventilated School Buildings." *Applied Energy* 94: 355–363.

Lieble, A., J. Haller, B. Jödicke, H. Baumgartner, S. Schlittmeier, and J. Hellbrück. 2012. "Combined Effects of Acoustic and Visual Distraction on Cognitive Performance and Well-Being." *Applied Ergonomics* 43: 424–434.

Madureira, J., I. Paciencia, E. Ramos, H. Barros, C. Pereira, J. P. Teixeira, and E. de Oliveira Fernandes. 2015. "Children's Health and Indoor Air Quality in Primary Schools and Homes in Portugal – Study Design." *Journal of Toxicology and Environmental Health, Part A* 78: 915–930.
Mendell, M. J., E. A. Eliseeva, M. M. Davies, M. Spears, A. Lobscheid, W. J. Fisk, and M. G. Apte. 2013. "Association of Classroom Ventilation with Reduced Illness Absence: a Prospective Study in California Elementary Schools." *Indoor Air* 23: 515–528.
Montazami, A., M. Wilson, and F. Nicol. 2012. "Aircraft Noise, Overheating and Poor Air Quality in Classrooms in London Primary Schools." *Building and Environment* 52: 129–141.
Mydlarz, C. A., R. Conetta, D. Connolly, T. J. Cox, J. E. Dockrell, and B. M. Shield. 2013. "Comparison of Environmental and Acoustical Factors in Occupied School Classrooms for 11–16 Year-old Students." *Building and Environment* 60: 265–271.
Nagano, K., and T. Horikoshi. 2014. "Development of Equi-comfort Charts Constituted with Temperature and Noise at 150 and 3 lx." Proceedings of Indoor Air 2014, Hong Kong.
Ortiz, M. A., D. Zhang, and P. M. Bluyssen. 2019. "Table Top Surface Preference of School Children Under Different Lighting Conditions Tested in the SenseLab." Proceedings CLIMA 2019, Bucharest.
Pan, Z., S. K. Kjaergaard, and L. Mølhave. 2003. "A Chamber Experiment Investigation of the Interaction between Perceptions of Noise and Odour in Humans." *International Archives of Occupational and Environmental Health* 78: 99–106.
Park, J. G. P. 2014. "Correlations Between Color Attributes and Children's Color Preferences." *Color Research and Application* 39: 452–462.
Pellerin, N., and V. Candas. 2003. "Combined Effects of Temperature and Noise on Human Discomfort." *Physiology & Behavior* 78: 99–106.
Pellerin, N., and V. Candas. 2004. "Effects of Steady-state Noise and Temperature Conditions on Environmental Perception and Acceptability." *Indoor Air* 14: 129–136.
RVO.nl. 2015. *Programma van Eisen Frisse scholen* 2015 [Programme of Demands Fresh Schools 2015]. Rijksdienst voor ondernemend Nederland. Accessed December 10, 2015. www.frisse-scholen.nl.
Seo, H. S., and T. Hummel. 2017. "Cross-modal Integration in Olfactory Perception." In *Springer Handbook of Odor*, edited by A. Buettner, 115–116. Cham: Springer. Springer Handbooks.
Shield, B. M., and J. E. Dockrell. 2003. "The Effects of Noise on Children at School: A Review." *Building Acoustics* 10: 97–116.
Simoni, M., I. Annesi-Maesano, G. Sigsgaard, D. Norback, G. Wieslander, W. Nystad, M. Canciani, P. Sestini, and G. Viegi. 2010. "School Air Quality Related to Dry Cough, Rhinitis and Nasal Patency in Children." *European Respiratory Journal* 35: 742–749.
Takaoka, M., K. Suzuki, and D. Nörback. 2016. "Sick Building Syndrome among Junior High School Students in Japan in Relation to the Home and School Environment." *Global Journal of Health Science* 8: 1–177.
Te Kulve, M., L. Schellen, L. J. M. Schlangen, and W. D. van Marken Lichtenbelt. 2016. "The Influence of Light on Thermal Response." *Acta Physiologica* 216: 163–185.
Toftum, J. 2002. "Human Response to Combined Indoor Environment Exposures." *Energy and Buildings* 34: 601–606.
Toftum, J., B. U. Kjeldsen, P. Wargocki, H. Mena, E. M. N. Hansen, and G. Clausen. 2015. "Association Between Classroom Ventilation Mode and Learning Outcome in Danish Schools." *Building and Environment* 92: 494–503.
Torresin, S., G. Pernigotto, F. Cappelletti, and A. Gasparella. 2018. "Combined Effects of Environmental Factors on Human Perception and Objective Performance: A Review of Experimental Laboratory Works." *Indoor Air* 28: 525–538.
Veitch, J. A. 1990. "Office Noise and Illumination Effects on Reading Comprehension." *Journal of Environmental Psychology* 10: 209–217.
Velasco, C., D. Balboa, F. Marmolejo-Ramos, and C. Spence. 2014. "Crossmodal Effect of Music and Odor Pleasantness on Olfactory Quality Perception." *Frontiers in Psychology* 5: 1–9.
Wargocki, P., and D. P. Wyon. 2007. "The Effects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children (RP-1257)." *HVAC&R Research* 13: 193–220.
WHO. 2015. *School Environment: Policies and Current Status*. Copenhagen: WHO Regional Office for Europe.
Winterbottom, M., and A. Wilkins. 2009. "Lighting and Discomfort in the Classroom." *Journal of Environmental Psychology* 29: 63–75.
Witterseh, T., D. P. Wyon, and G. Clausen. 2004. "The Effect of Moderate Heat Stress and Open-plan Office Noise Distraction on SBS Symptoms and on the Performance of Office Work." *Indoor Air* 14: 30–40.
Yildirim, K., K. Cagatay, and N. Ayalp. 2015. "Effect of Wall Colour on the Perception of Classrooms." *Indoor and Built Environment* 24: 607–616.
Zhang, D., M. Ortiz, and P. M. Bluyssen. 2019. "Clustering of Dutch School Children Based on Their Preferences and Needs of the IEQ in Classrooms." *Building and Environment* 147: 258–266.
Zhang, D., M. J. Tenpierik, and P. M. Bluyssen. 2019. "The Effect of Acoustical Treatment on Primary School Children's Performance, Sound Perception, and Influence Assessment." Proceedings CLIMA 2019, Bucharest.