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Clustering of Dutch school children based on their preferences and needs of the IEQ in classrooms

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ABSTRACT

Background: It is well-known that indoor environmental quality (IEQ) in classrooms can have an effect on school children's comfort, health and performance. Unfortunately, information about the school children's perception of IEQ factors in their classrooms is still insufficient. The objective of this study was to better understand school children's IEQ preferences and needs in classrooms.

Methods: Perceptions, preferences, and needs regarding the IEQ in classrooms were collected by a questionnaire from 1145 school children (9–12 years) in 21 primary schools (54 classrooms) in the Netherlands. Descriptive analysis, correlation analysis, principal component analysis and two-step cluster analysis were used to analyse the data.

Results: Using two-step cluster analysis, this study identified six clusters (profiles) of children based on their comfort perceptions and the importance of environmental factors. Among them, four clusters of children had specific concerns related to the IEQ factors: the 'Sound concerned cluster', the 'Smell and Sound concerned cluster', the 'Thermal and Draught concerned cluster', and the 'Light concerned cluster'. However, the other two clusters of children did not show a specific concern, the 'All concerned cluster' was concerned about all IEQ factors in the classroom, while the 'Nothing concerned cluster' did not show any concern.

Conclusion: This study allows for a better understanding of the preferences and needs of primary school children from their own perspective and provides a foundation for future studies to improve both the IEQ in classrooms and school children's comfort and health.

1. Introduction

Indoor environmental quality (IEQ), which includes indoor air quality, acoustical quality, visual quality, and thermal quality, affects occupants' comfort, health, and performance. These influences might be more obvious in classrooms, because children are more sensitive to environmental conditions than adults, especially to environmental pollutants and acoustics [1]. As a result, IEQ in classrooms and its impact on school children has attracted much attention in the last decades. Many studies have shown the influence of indoor air quality (IAQ) [2,3], thermal comfort [4], light [5], and noise [6] on children at school, and these studies were performed in many countries around the world, for example in Italy [7], in Finland [8], in the US [9], in China [10], in Australia [11], in Turkey [12] and in Malaysia [13]. However, most of these studies just concerned one or two of the four factors of IEQ, problems concerning all factors of IEQ in classrooms have hardly been addressed [14].

Additionally, as part of a large field study that was conducted in 54 classrooms of 21 primary schools in the Netherlands [15], it was found that teachers cannot fulfil every child's needs related to the IEQ in the classroom [16]. It was concluded there are two reasons for this: 1) each child has different needs; the teacher present cannot respond to each of these needs and 2) even if the teacher was able, there would not be enough available options in a classroom for the teacher to change or adapt the environment.

To create an efficient learning environment, many studies have been conducted to find effective solutions to improve the IEQ of classrooms. However, most of these solutions have been developed based on objective measurements [17] or simulations [12,18] of IEQ factors in classrooms in relation to criteria set-up for adults, or were focused on financial gains [19]. Although school children were the target group in such studies, it seems that a classroom is nevertheless designed for adults. Fortunately, there are still several studies in which children were involved. For example, a study conducted in two schools in Malaysia showed that children were dissatisfied with the level of noise and air movement [13]. And in a study conducted by Valeski and Stipek, it

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was found that the way school children feel about their school has an impact on their academic performance [20]. Almost all of these studies assessed children's perceptions or feelings, however none of them did further research into children's needs and preferences of the IEQ in their classrooms.

Despite this research gap, it is worth mentioning that the similar studies about the needs and preferences of adults have been carried out in the office environment. Based on the results of these studies, several so-called Individually Controlled Devices (ICDs) have been designed and developed. These ICDs are meant to provide individual or personal control of the local environment, and can be divided into four types corresponding to the four factors of IEQ:

- Heated or cooled chairs [21,22] and heating radiant panels [23].
- Personal ventilation [24,25] and local air vents [25].
- Task-ambient light [26,27].
- Headphones [28] and sound masking [29].

For improving IEQ, some European guidelines suggest that individual control of the micro-environment of each occupant is required [30], and therefore makes the use of ICDs an interesting topic of research. However, although the aforementioned ICDs have shown to be beneficial for some office workers, research on children's preferences of the different IEQ factors is insufficient to conclude whether these particular ICDs could be useful for school children as well.

The objective of this study was therefore firstly: to identify the needs of children for the four IEQ factors in classrooms and their preferences for a selection of ICDs, because collecting every child's needs and preferences for IEQ in classrooms and to design specific solutions for each child is too meticulous. The second objective was: to investigate whether it is possible to cluster the school children based on their comfort perceptions and importance of environmental factors, as is often used in market research to segment customers according to their needs and preferences [31,32].

2. Methods

2.1. Data collection

The underlying study is part of a larger field study that was conducted in 54 classrooms of 21 primary schools in the Netherlands in the spring of 2017 [15]. Out of the 21 primary schools studied, 17 schools (40 classrooms) (with 949 children) apply the traditional educational system, while the remaining five schools (14 classrooms) (with 196 children) adopt a more flexible education approach based on different educational theories such as Jena, Montessori or Dalton. Based on that, in this study, these two different types of schools were named “traditional schools” and “non-traditional schools”, respectively. The survey involved 1145 school children, consisting of 577 boys and 568 girls with a mean age of 10 years (9−12). All parents of the participating children were informed before the survey and they all signed a consent letter to allow their children to participate in this survey. Researchers handed out the questionnaire to every child in their own classrooms and collected the questionnaires as soon as the children were finished. Participants were given the opportunity to skip any questions or even withdraw their participation at any time. The detailed information about the selection of schools and the general procedure of the survey is presented in Bluyssen et al. [15].

The children's questionnaire was based on the questionnaires used in SINPHONIE [33], a European-wide study in schools, and on a visual comfort study performed in Italy [34]. It contained five parts: general questions, questions about health, questions about the classroom environment, questions about individual control, and questions about their home. The questionnaire was made of 37 questions in total, and on average participants spent about 30 min to fill it out. In order to help children understand some of the questions, a few cartoon illustrations were included in the questionnaire. Besides, a short introduction was given before children filled in the questionnaire, and they could ask the researchers present in case they were confused about the questions.

This paper focuses on the questions concerning classroom environment and individual control. For the classroom environment, children's perceptions of comfort in terms of temperature, draught, smell, noise, and light in their classrooms are included. For individual control, two questions are included: the preference for six existing ICDs (including a heated chair, a heated desk, a heated back, a desk lamp, a personal ventilator and a headphone), and the importance of 10 indoor environmental factors to the children's school performance (including feet temperature, air temperature, chair temperature, scent, fresh air, light on desk, light on board, hearing teacher, outdoor sound, indoor sound). These factors were rated on a scale from 0 to 10 (10: very important, 0: not important at all). This rating is named the ‘importance index’ in this paper.

2.2. Data analysis

The data were analysed in four steps using SPSS version 23.0 (SPSS Inc. Chicago, IL, USA). First, the basic information (e.g. the mean and standard deviation of school children's comfort perceptions, importance indexes of environmental factors, preferences of ICDs) using descriptive analysis. The answers of school children were analysed at classroom level. It is worth mentioning that a new database was created based on the mean values in each classroom, and all the analysis conducted at classroom level was based on this new database.

Then, the relationships between school children's comfort perceptions and their preferences for ICDs were determined, not only at classroom level using bivariate correlations, but also at the individual level using Chi-squared tests. It should be noted that both the descriptive analysis and correlation analysis were conducted not only for all data together, but also for the traditional schools and non-traditional schools separately, since the differences in responses between the two types of schools could not be ignored [15].

Next step was the principle components analysis (PCA), which is recommended as the preparational step of any multivariate analysis to identify the structure of the dataset. It has several functions, such as data reduction, outlier detection, variable selection, and so on [35]. The PCA was used to simplify the original data into a smaller number. Reflecting the large proportion of information contained in the original ones. It can be seemed as the data preparation for the next analysis, namely cluster analysis. As recommended by Field [36], the detailed setting of this analysis was as follows: the extraction was based on eigenvalues (Eigenvalues over 1); the rotation method was varimax; the cases with missing values were pairwise excluded (exclude the cases pairwise); and 0.4 was seen as a significant factor loading (suppress absolute values less than 0.4). This analysis was performed on the variables related to children's comfort perceptions and importance indexes, separately.

Lastly, the two-step cluster analysis was conducted using the new variables (components) identified by the PCA. The two-step cluster analysis has several reasons to be selected as the method in this study. Firstly, it is the only type of cluster analysis that permits continuous and categorical data to be analysed simultaneously. Secondly, two-step cluster analysis automatically selects the optimal number of clusters. Thirdly, it is suitable for large data sets [37,38]. Besides, the two-step cluster analysis has been successfully used before in research studies [37] and has been proven to be an adequate approach to identify occupants’ archetypes [39].

In this analysis, only traditional school children's data were used, because of the significant difference between children of traditional and non-traditional schools and the insufficient data of non-traditional school children. For the detailed setting of the two-step cluster analysis, the option of optimum number of clusters, log-likelihood distance measure and Akaike's Information Criterion were selected. After the

analysis, according to Norušis [38], four tests were conducted to validate the final solution model. The first test is to determine the silhouette coefficient which is a measure of cohesion and separation that should be higher than the recommended level 0.0. Secondly, Chi-squared tests and ANOVA are conducted, to confirm that each variable was statistically significant related to these clusters. The third test checks whether all variables have a predictor importance higher than 0.02. Finally, in the last test the database is randomly split into two, and the final solution is applied to each of them, in order to check whether the outcome is similar.

3. Results

3.1. Descriptive analysis

The field study [15] collected children's comfort perceptions in classrooms by directly asking them 'Can you hear/smell/see … '. If they gave an affirmative answer (yes or sometimes), then they needed to answer a follow up question: 'Are you bothered by the noise/smell/light … ?'. The affirmative answers to these questions were regarded as discomforts in this study. In general, as has been reported in Ref. [15], children felt less comfortable in classrooms of traditional schools than in non-traditional ones. 'Noise' caused the most discomfort (87% felt uncomfortable), 'Smell' was second (63% was bothered), sunlight third (42% was bothered), followed by 'Thermal discomfort' (35% was bothered), and 'Artificial light' and 'draught' came last (12% and 8% was bothered, respectively).

Fig. 1 illustrates the mean value and standard deviation of the importance indexes of environmental factors. In general, all the importance indexes were higher in the traditional classrooms than in the non-traditional ones. 'Hearing teacher', with the highest average score and the lowest standard deviation (8.6 ± 0.55 for all classrooms, 8.6 ± 0.58 for traditional classrooms, 8.4 ± 0.34 for non-traditional classrooms) ranked first. This means children thought that 'Hearing teacher' is the most important impact on their school performance. The second and third most important factors were 'Fresh air' (7.9 ± 0.69 for all classrooms, 8.0 ± 0.68 for traditional classrooms, 7.5 ± 0.57 for non-traditional classrooms) and 'Air temperature' (7.2 ± 0.79 for all classrooms, 7.4 ± 0.70 for traditional classrooms, 6.5 ± 0.78 for non-traditional classrooms). 'Chair temperature' and 'Feet temperature' were the two least important factors, with average importance indexes lower than 5.0 (around 5.0 for traditional classrooms, around 4.2 for non-traditional classrooms), which could indicate that children didn't think the feet temperature and chair temperature are important for their school performance.

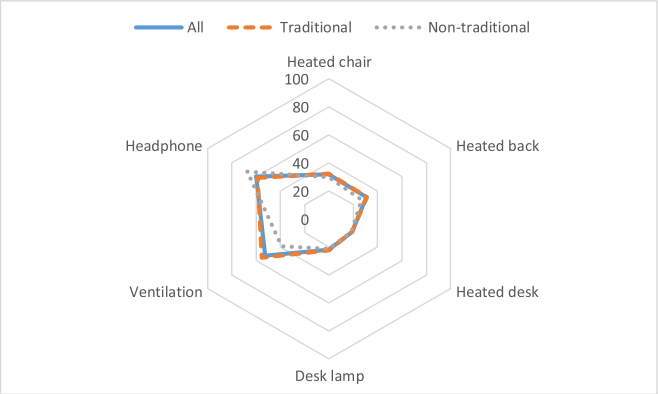

Fig. 2. Preference of the ICDs indicated by the school children.

Fig. 2 depicts the results of the school children's preferences for ICDs. The most preferred device, according to the children' answers, was 'Headphone': around 60% of the children in a classroom of both traditional and non-traditional schools, indicated that they wanted to have a headphone. This combined with the highest importance index of 'hearing teacher' might indicate that the acoustical quality was the biggest problem for almost all the classrooms. The 'Ventilator at desk' was the second most favourite device: 53% of children, on average, in a classroom expressed interest in it. This also corresponded to the second and the third highest importance index of 'Fresh air' and 'Air temperature'. With respect to the other devices, only less than one third of children preferred to have them. From the comparison of the results of the traditional and the non-traditional schools, it can be concluded that the 'Headphone' is the only device that was more preferred by children from non-traditional schools, while all the others were more preferred by children from traditional schools.

3.2. Correlation analysis

Table 1 shows the relationship between school children's perceived comfort conditions and their preferences for ICDs. Almost no statistically significant relationship was found at classroom level, except for

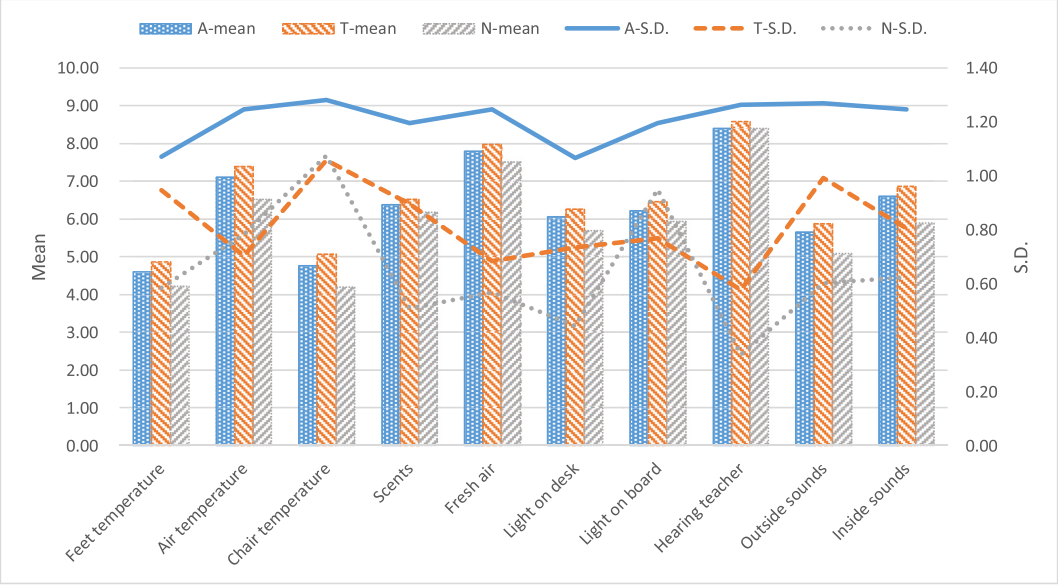

Fig. 1. Importance index of indoor environmental factors in all (A), traditional (T), and non-traditional (N) classrooms.

Table 1
Correlations between school children's comfort perceptions and their preference of ICDs.

Comfort perceptions	Preference of ICDs	All classrooms (P_A)		Traditional classrooms (P_T)		Non-traditional classrooms (P_N)	
		Classroom Level	Child level	Classroom level	Child level	Classroom level	Child level
Thermal discomfort	Heated chair	0.158	0.809	0.311	0.961	0.075	0.805
	Heated back	0.244	**0.023**	0.382	0.104	0.252	0.076
	Heated desk	0.075	0.213	0.178	0.413	0.130	0.238
Bothered by draught	Ventilator at desk	**0.003**	**0.000**	**0.003**	**0.000**	0.197	**0.036**
Bothered by smell	Ventilator at desk	0.096	**0.000**	0.128	**0.005**	0.342	**0.019**
Bothered by sunlight	Desk lamp	0.779	**0.016**	0.355	**0.034**	0.112	0.258
Bothered by artificial light	Desk lamp	0.851	0.082	0.680	0.103	0.780	0.664
Bothered by noise	Headphone	0.636	**0.000**	0.302	**0.001**	0.915	0.180

Note: P_A, P_T, P_N: p-values of Spearman's rank and Chi-squared test for class level and child level respectively; p-values in bold highlighted are the correlations with statistical significance ($P < 0.05$).

the one between 'bothered by draught' and 'preference for a ventilator' for the classrooms of all schools ($P_A = 0.003$) as well as for the classrooms of the traditional schools separately ($P_T = 0.003$).

At child level, relationships were found for all aspects. For the thermal aspect, the statistically significant relationship was only found between all school children's 'preference for a heated back' and their 'thermal discomfort' ($P_A = 0.023$). For the air aspect, all school children's 'annoyance by draught' and 'smell' were related to their 'preference for a ventilator' ($P_A = 0.000$), and these relationships were also found among children of traditional schools and children of non-traditional schools separately (for draught, $P_T = 0.000$, $P_N = 0.036$; for smell, $P_T = 0.005$, $P_N = 0.019$). For the visual aspect, all school children's 'annoyance by sunlight' was related to their 'preference for a desk lamp' ($P_A = 0.016$), while if separated these children based on their school type, then this relationship could only be found among traditional school children ($P_T = 0.034$). For the acoustical aspect, school children's 'annoyance by noise' was related to their 'preference for a headphone' ($P_A = 0.000$), while this relationship can only be found among traditional school children ($P_T = 0.001$) as well. These relationships indicate that every child's preference was only related to his or her own comfort perception, and these relationships could not be generalized at classroom level.

Table 2 shows the results of correlations between school children's comfort perceptions and the importance indexes of environmental factors. No relationship was found at classroom level except for the air aspect. For air quality, in all classrooms, the percentage of children 'bothered by smell' was related to the 'importance of scents' ($P_A = 0.023$). In classrooms of traditional schools, relationships were established between the percentage of children 'bothered by smell' and the 'importance of scents' ($P_T = 0.042$), and between the percentage of children 'bothered by smell' and the 'importance of fresh air' ($P_T = 0.049$). While in classrooms of non-traditional schools, a relationship was found between the percentage of children 'bothered by draught' and the 'importance of scents' ($P_N = 0.021$).

At child level, relationships were found in both visual and acoustical aspects. For visual quality, 'bothered by sunlight' was related to the 'importance of light on desk' for all school children ($P_A = 0.008$), and it was also true among children of traditional schools separately ($P_T = 0.013$), while for children of non-traditional schools, a relationship was found between 'bothered by artificial light' and the 'importance of light on board' ($P_N = 0.032$). For acoustical quality, all school children's perception of 'bothered by noise' was related to the 'importance of outside sounds' ($P_A = 0.005$) and the 'importance of inside sounds' ($P_A = 0.005$), while it was only related to the 'importance of inside sounds' for children of traditional schools ($P_T = 0.028$) and only related to the 'importance of outside sounds' for children of non-traditional schools ($P_N = 0.009$). However, for the thermal aspect, no relationship, neither at classroom level nor at child level, could be found between children's 'thermal discomfort' and the 'importance of temperature'.

3.3. Principal component analysis

Using PCA, three components were identified related to comfort perceptions. Component 1 has a substantial loading for 'bothered by sunlight' and 'bothered by artificial light'. These variables are important for learning: they both influence the way reading on the board and/or at the desk. Therefore, component 1 was labelled as 'discomfort -

Table 2
Correlations between school children's comfort perceptions and importance indexes.

Comfort perceptions	Environmental factors	All classrooms (P_A)		Traditional classrooms (P_T)		Non-traditional classrooms (P_N)	
		Classroom level	Child level	Classroom level	Child level	Classroom level	Child level
Thermally uncomfortable	Feet temperature	0.934	0.623	0.369	0.376	0.699	0.115
	Air temperature	0.138	0.575	0.605	0.777	0.864	0.585
	Chair temperature	0.512	0.933	0.079	0.676	0.781	0.618
Bothered by draught	Scents	0.976	0.218	0.783	0.367	**0.021**	0.330
	Fresh air	0.615	0.125	0.362	0.086	0.728	0.868
Bothered by smell	Scents	**0.023**	0.053	**0.042**	0.081	0.185	0.791
	Fresh air	0.054	0.702	**0.049**	0.922	0.932	0.913
Bothered by sunlight	Light on desk	0.739	**0.008**	0.975	**0.013**	0.137	0.511
	Light on board	0.669	0.162	0.492	0.397	0.516	0.150
Bothered by artificial light	Light on desk	0.604	0.147	0.782	0.057	0.578	0.168
	Light on board	0.904	0.554	0.816	0.209	0.881	**0.032**
Bothered by noise	Hearing teacher	0.376	0.654	0.632	0.620	0.271	0.723
	Outside sounds	0.106	**0.005**	0.293	0.118	0.634	**0.009**
	Inside sounds	0.086	**0.005**	0.379	**0.028**	0.527	0.134

Note: P_A, P_T, P_N: p-value of Spearman's rank.
p-values in bold highlighted are the correlations with statistical significance ($P < 0.05$).

related to learning'. Component 2 had a loading for 'bothered by smell' and 'bothered by noise', which are annoyances caused by fellow classmates, according to the children's answers, therefore component 2 was labelled as 'discomfort - related to classmates'. Component 3 had high loading for 'thermal discomfort' and 'bothered by draught' which are both about the classroom conditions, so component 3 was labelled as 'discomfort – related to classroom conditions'.

With respect to the importance indexes, the result of PCA suggested four components. 'Feet temperature' and 'chair temperature' were highly loaded in Component 1 and named 'important – temperature'. 'Fresh air', 'air temperature' and 'scent' were loaded in Component 2, which was therefore named 'important – air'. 'Light on board', 'light on table' and 'hearing teacher' were loaded in Component 3 and named 'important – learning media. And the other variables about sound were loaded in Component 4 and named 'important – sound'.

3.4. Two-step cluster analysis

In order to categorize the children of traditional schools, a two-step cluster analysis was conducted using the new variables generated by the PCA, and revealed six clusters, with 680 children (269 children, as incomplete sample, were automatically excluded by the process of factor analysis and Two-step analysis). The silhouette coefficient of the final solution is 0.3. The predict importance of these variables in the final solution were: comfort-smell and noise (1.00) and comfort -thermal and draught (0.83), followed by important-temperature (0.35), comfort-light (0.27) and important - light (0.21), important -air being the least important (0.04). And all of these variables were confirmed to be statistically significant related to the six clusters. Additionally, after splitting the database in halves, only minor changes occurred (Table 3). All of these indicated that the six-cluster solution was justified [38].

3.5. Description of clusters

The description of clusters was based on data related to the school children's general and personal information, health status, comfort perceptions, preferences for ICDs, and the importance indexes of environmental factors. All of this information is presented in Table 4.

3.5.1. Cluster 1: sound concerned

Personal information. Cluster 1 was the largest cluster with a sample size of 150, including 77 (51.3%) girls and 73 (48.7%) boys, representing 22.1% of all cases. The average age of children in Cluster 1 was 10.0 years (SD = 1.3). This cluster had the smallest percentage (10.7%) of children who wore glasses/lenses. Besides, it also had the smallest percentage of children who came to school by walking, the largest percentage of children who came by bike, and the remaining 15.3% of children came by car.

Characteristics of children. The first cluster represented the highest percentage of children bothered by noise (100.0%). Besides, the percentage of children bothered by smell (94.0%) was also slightly higher compared to other clusters. However, the other discomfort perceptions were not obvious in this cluster, the percentage of children bothered by thermal discomfort (34.0%), draught (0.7%), sunlight (34.0%) and artificial light (3.3%) were all lower than the average levels. For the importance of 10 environmental factors, children in cluster 1 represented a relatively negative opinion, except for the outside sound (7.5) and inside sound (8.5), which were the highest among all the clusters. But for the others, such as feet temperature (2.8), chair temperature (3.3), light on table (5.2) and light on board (5.4), the importance indexes were the lowest among all clusters. Considering its highest percentage of children bothered by noise and highest importance indexes of indoor sound and outdoor sound, this cluster was named the 'Sound concerned cluster'.

Health condition of children. In general, children in cluster 1 had a high incidence of diseases. The percentage of the children who reported suffering from bronchitis (4.7%), was highest among all clusters; for hay fever (16.4%), rhinitis (23.4%), allergies (27.7%) and eczema (19.3%), the percentages of children were higher than the average level. Only the prevalence of diabetes (0.0%) and asthma (4.7%) were lower than in other clusters. In terms of building-related symptoms, the most prevalent ones were difficulty breathing (8.8%) and dry, itchy skin (10.1%). The other symptoms showed lower prevalence in this cluster, with the lowest prevalence of dry eyes (5.5%), stuffy nose (6.7%), runny nose (7.5%) and headache (14.1%), and the second lowest prevalence of itchy eyes (14.2%), sneezing (14.0%), and dry throat (9.5%).

Preference of ICDs. Cluster 1 showed lower preference for the offered ICDs. Children in this cluster had the lowest percentage who reported their preference for a heated chair (24.0%), a heated desk (13.3%), and a desk lamp (21.3%), the second lowest percentage who reported desire for a heated back (24.0%). Only for a ventilator (60.0%) and headphones (62.0%), more than half children in this cluster reported they wanted to have them, but these percentages were still lower than the average level.

3.5.2. Cluster 2: all concerned

General information. Cluster 2 was the youngest group, with an average age of 9.8 years (SD = 1.6). It comprised of 80 (58.4%) girls, which was the highest girls' proportion among all clusters, and 57 (41.6%) boys, in total 137 children which represented 20.1% of the whole database. About 18% of children in this cluster wore glasses/lenses. For commuting, the ratio of walking, bike and car was 4:5:1.

Characteristics of children. Cluster 2 had a relatively high percentage of children bothered by thermal discomfort (42.3%), smell (97.8%), noise (100.0%) and sunlight (63.5%), while a relatively low percentage of children bothered by draught (0.0%) and artificial light (8.8%). Children in cluster 2 reported the second highest average importance index for the 10 environmental factors, and these important indexes varied in a small range, only from 6.7 to 8.0. This means that for these children, all of those factors are relatively important for their school

Table 3
Cluster input with predicter importance.

Predictor importance	Final solution	First half solution	Second half solution
0.60–1.00	· Discomfort - classmates (1.00) · Discomfort - classroom conditions (0.93) · Discomfort - learning aspects (0.60)	· Discomfort - classmates (1.00) · Discomfort - classroom conditions (0.66) · Discomfort - learning aspects (0.65)	· Discomfort - classmates (1.00) · Discomfort - classroom conditions (0.82) · Discomfort - learning aspects (0.73)
0.20–0.59	· Important – temperature (0.39) · Important - sound (0.30)	· Important – learning media (0.35)	· Important – air (0.37) · Important – learning media (0.28)
0.00–0.19	· Important – learning media (0.05) · Important – air (0.02)	· Important – temperature (0.17) · Important – air (0.06) · Important - sound (0.02)	· Important – temperature (0.09) · Important - sound (0.04)

Table 4
Characteristics of school children in different clusters.

	C1-22.1%	C2-20.1%	C3-19.1%	C4-11.6%	C5-7.8%	C6-19.3%	Total
Personal information							
Gender							
Girl	51.3	58.4	53.1	57.0	50.9	47.3	52.9
Boy	48.7	41.6	46.9	43.0	49.1	52.7	47.1
Age (mean)	9.99	9.83	9.92	10.10	10.40	10.15	10.07
Ware glass/lenses							
Yes	10.7	17.5	15.5	23.4	18.9	16.8	16.2
No	89.3	82.5	84.5	76.6	81.9	83.2	83.8
Commute methods							
Walking	33.3	40.4	36.7	36.7	52.8	41.2	38.8
Biking	51.3	49.3	47.7	46.8	34.0	51.1	48.3
Car	15.3	10.3	15.6	16.5	13.2	7.6	12.9
Commute time (mean)	6.53	6.55	6.91	6.68	6.35	7.01	6.73
Position in class (vertical)							
Front	37.6	43.5	34.9	35.9	26.5	30.7	36.0
Middle	41.6	42.6	48.6	40.6	41.2	48.5	44.4
Back	20.8	13.9	16.5	23.4	32.4	20.8	19.6
Near the window	52.9	49.4	56.5	56.1	52.8	47.5	52.3
- Neat the door	36.5	39.1	37.6	26.3	41.7	36.3	36.3
Near the window and door	10.6	11.5	5.9	17.5	5.6	16.3	11.4
Disease							
Asthma*	4.7	6.7	2.4	12.8	15.1	4.7	5.3
Bronchitis	4.7	0.0	1.4	2.3	2.7	1.2	1.9
Hay fever*	16.4	19.8	14.3	19.7	30.8	8.8	16.2
Rhinitis	23.4	19.7	15.9	18.4	32.1	12.7	18.7
Allergies*	27.7	22.1	24.2	23.4	47.2	21.6	25.0
Eczema*	19.3	16.8	20.5	13.2	34.0	9.5	17.2
Diabetes	0.0	2.1	0.0	0.8	0.0	0.0	0.6
Symptoms							
Dry eyes	5.5	7.4	5.6	9.0	17.6	8.6	7.6
Itchy eyes*	14.2	16.2	9.4	18.2	27.5	16.3	15.3
Stuffed nose	6.7	15.3	8.7	16.7	17.6	9.9	11.3
Runny nose	7.5	11.8	12.7	11.8	10.0	10.1	10.3
Sneezing	14.0	18.5	21.1	11.5	28.8	15.4	17.2
Dry throat	9.5	16.2	10.3	13.2	26.0	9.4	12.4
Difficult breathing*	8.8	7.4	0.8	9.1	10.0	7.8	6.8
Dry, itchy skin*	10.1	6.6	6.3	5.1	19.6	2.3	7.2
Headache	14.1	19.0	22.7	17.9	21.2	15.3	17.8
Comfort perception							
Thermal discomfort**	34.0	42.3	40.8	62.0	43.4	27.5	39.7
Bothered by draught**	0.7	0.0	2.3	100.0	5.7	0.8	12.8
Bothered by smell**	94.0	97.8	100.0	84.8	73.6	22.1	79.4
Bothered by noise**	100.0	100.0	100.0	94.9	96.2	58.0	91.0
Bothered by sunlight**	34.0	63.5	36.9	43.0	94.3	25.2	44.6
Bothered by artificial light**	3.3	8.8	0.0	16.5	100.0	2.3	12.6
Importance index							
Feet temperature**	2.8	7.1	4.9	5.6	5.9	4.6	5.1
Air temperature**	6.5	7.9	8.1	6.9	8.0	6.9	7.4
Chair temperature**	3.3	7.8	4.6	5.5	6.5	4.4	5.3
scent**	6.6	6.9	6.4	6.9	7.0	6.4	6.7
Fresh air**	7.9	7.4	8.7	7.6	8.2	8.1	8.0
Light on table**	5.2	6.9	6.6	6.7	7.8	6.2	6.6
Light on board**	5.4	6.7	6.9	7.1	7.8	6.6	6.8
Hearing teacher**	8.6	8.0	9.4	8.2	8.9	9.0	8.7
Outside sound**	7.5	7.0	2.8	6.9	6.6	5.3	6.0
Inside sound**	8.5	7.1	5.0	7.2	7.1	6.5	6.9
Preference							
Heated chair**	24.0	42.3	34.6	48.1	45.3	26.0	34.6
Heated back**	24.0	42.3	33.8	53.2	49.1	21.4	34.4
Heated desk**	13.3	24.1	20.8	38.0	39.6	13.7	21.9
Desk lamp*	21.3	29.2	23.8	24.1	22.6	22.1	24.0
Ventilator**	60.0	61.3	67.7	41.8	66.0	49.6	58.1
Headphone*	62.0	68.6	55.4	65.8	69.8	56.5	62.1

Notes: * means $p < 0.05$;** means.$p < 0.001$

performance. The high percentages of children bothered by almost all factors of IEQ and high importance indexes for all factors made this cluster to be the 'All concerned cluster'.

Health condition of children. Cluster 2 had the highest percentage of children with diabetes (2.1%), and the lowest percentage of children with bronchitis (0.0%), while the other diseases were close to the average level. For building-related symptoms, this cluster had a relatively high prevalence, with a higher than average percentage of children suffering from almost all symptoms except for dry eyes (7.4%) and dry itchy skin (6.6%).

Preference of ICDs. Children in cluster 2 showed interests in all of the six offered ICDs. Most of the children were interested in a desk lamp (29.2%), the second largest percentage of children who wanted to have headphones (68.6%), and the third largest percentage who wanted to have the other devices. All in all, in cluster 2 the percentages of children who wanted to have these devices were all higher than the average level.

3.5.3. Cluster 3: Smell and Sound concerned

General information. Cluster 3 comprised of 130 children, including 69 (53.1%) girls and 61 (46.9%) boys, representing 19.1% of the database. The average age of children in this cluster was 9.9 years (SD = 1.6). 15.5% of them wore glasses/lenses. For commuting to school, about 37% of children in this cluster selected walking, 48% selected bike, and 16% selected car.

Characteristics of children. The discomfort perceptions reported by children in cluster 3 mainly concerned noise and smell; all children in this cluster were bothered by them. However, no child in this cluster reported being bothered by artificial light. The percentages of children who were bothered by the other discomfort sources had average levels. Children in this cluster showed the largest range of Importance index scores: from 2.8 to 9.4. This cluster reported the highest importance indexes for air temperature (8.1), fresh air (8.7) and hearing the teacher (9.4), and the lowest importance indexes for scent (6.4), outside sound (2.8) and inside sound (5.0). For the other factors, the importance indexes reported in this cluster were around the average level. Children in this cluster considered noise and smell as the most annoying aspects, and also reported the highest importance indexes for fresh air and hearing the teacher well. Therefore, this cluster was named the 'Sound and Smell concerned cluster'.

Health condition of children. In general, children in cluster 3 had relatively low incidences of diseases. The percentage of children suffered from asthma (2.4%) and diabetes (0.0%) were the lowest among all clusters. Bronchitis (1.4%), hay fever (14.3%), rhinitis (15.9%), and allergies (24.2%), were also lower than the average level. While only eczema (20.5%) had the second highest prevalence among all clusters. With respect to building-related symptoms, in cluster 3, the top three were headache (22.7%), sneezing (21.1%) and runny nose (12.7%), and the percentages of children suffering from these symptoms were either the highest or the second highest among all clusters. However, for other symptoms, the percentages were lower than the average level.

Preference of ICDs. Cluster 3 presented the highest percentage of children who preferred a ventilator (67.7%). Children in this cluster didn't show much interest in the other devices: preferences for other devices were all lower than average and especially for headphones (55.4%), which presented the lowest percentage among all clusters.

3.5.4. Cluster 4: thermal and draught concerned

General information. Cluster 4 was the second smallest cluster, with the second highest percentage of girls. It comprised of 79 children, including 45 (57.0%) girls and 34 (43.0%) boys, representing 11.6% of the database. The average age of children in this cluster was 10.1 years (SD = 1.44). Cluster 4 was the cluster with the highest percentage (23.4%) of children who wore glasses/lenses, it also had the highest percentage (16.5%) of them came to school by car.

Characteristics of children. In general, children in cluster 4 felt more discomfort than the others. This cluster had higher than average percentages of children who reported being bothered by almost all the discomfort sources except the sunlight which still rated third highest. Besides, it had the highest percentages for bothered by thermal discomfort (62.0%) and draught (100.0%). Interestingly, the importance indexes distribution in cluster 4 was almost the opposite of cluster 3, which means that the factors with higher scores in cluster 3 were always rated lower in this cluster and vice versa. For example, children in cluster 4 reported the lowest score for air temperature (6.9), and the second lowest score for fresh air (7.6) and hearing teacher (8.2), while cluster 3 had the highest importance indexes for these factors. For the other seven factors, children in this cluster rated higher than average scores and higher than the scores reported by cluster 3 as well. Cluster 4 was named the 'Thermal and Draught concerned cluster' because it had the highest percentages of children bothered by thermal discomfort and draught.

Health condition of children. Cluster 4 had an average health status compared to the other clusters. Neither the highest nor the lowest prevalence of any disease appeared in this cluster. While for the building-related symptoms, children in cluster 4 reported the unhealthiest status. The prevalence of almost all the symptoms were higher than average, only the prevalence of sneezing (11.5%) and dry, itchy skin (5.1%) were lower than the average.

Preference of ICDs. Cluster 4 had the highest percentages of children preferring a heated chair (48.1%) and a heated back (53.2%) and the second highest percentage of children preferring a heated desk (38.0%). Such preferences correspond to these children's thermal discomfort perceptions. Besides, this cluster had the lowest percentage of children preferring a ventilator, which might be related to their annoyance caused by draught. For the desk lamp (24.1%) and headphones (65.8%), the percentages were around the average level.

3.5.5. Cluster 5: light concerned

General information. Cluster 5 was the smallest cluster with 53 children, of which 27 (50.9%) were girls, representing 7.8% of the whole database. It is also the oldest cluster, with a mean age of 10.4 years (SD = 1.02). About 18.9% of children wore glasses/lenses. More than half, which was the highest percentage, of them came to school by walking, while only 34%, which was the lowest percentage, of them came by bike.

Characteristics of children. Children in cluster 5 were prone to be bothered by light; this cluster had the largest percentages of children who considered sunlight (94.3%) and artificial light (100.0%) as sources of annoyance. It also has the second largest percentage reporting thermal discomfort. As far as the importance indexes were concerned, this cluster presented the highest average importance indexes, and all its indexes were higher than average. In addition, they reported the highest rating for scent (7.0), light on table (7.8) and light on board (7.8), which might be related to their annoyances caused by sunlight and artificial light. Cluster 5 was named the 'Light concerned cluster' because it has the highest percentages of children bothered by sunlight and artificial light, and these children also reported the highest importance indexes for light on table and light on board.

Health condition of children. Cluster 5 had the worst health status. It had

the highest prevalence for three conditions: hay fever (21.2%), rhinitis (26.8%) and allergies (29.1%), and the second highest prevalence of the other three diseases: asthma (7.9%), bronchitis (2.7%) and eczema (19.3%). This cluster also had the highest provenance of building-related symptoms. It had the highest percentages of children suffering from almost all the symptoms except headache (21.2%) and runny nose (10.0%).

Preference of ICDs. Children in cluster 5 showed a relatively higher interest in almost all of the ICDs. The percentages of children who wanted to have headphones (69.8%) and a heated desk (39.6%) were the highest, and the percentages of children who preferred a heated chair (45.3%), a heated back (49.1%) and a ventilator (64.7%) were the second highest. The desk lamp (22.6%), however, had a lower than average level, and this might due to the fact that all the children in the cluster reported being bothered by artificial light.

3.5.6. Cluster 6: nothing concerned

General information. This cluster comprised of 131 children, 22.0% of the whole database, and it has the largest percentage of boys (52.7%). The average age of children in this cluster is 10.2 years (SD = 0.93). 17% of them wore glasses/lenses. It was the cluster with fewest (7.6%) children coming to school by car.

Characteristics of children. Children in cluster 6 felt more comfortable than the rest, the percentages of children bothered by the assessed IEQ sources were much lower than the average levels. Besides, this cluster had the lowest percentage for being bothered by thermal aspects (27.5%), smell (22.1%), noise (58.0%), and sunlight (25.2%). The importance indexes reported by children were relatively lower. They rated the lowest scores for air temperature (6.3) and scent (6.4), and the second lowest scores for feet temperature (4.6), chair temperature (4.4), light on table (6.2), light on board (6.6), outside sound (5.3) and inside sound (6.5). The low percentage of children bothered by all of the IEQ aspects of classrooms and the low important indexes of the factors made this cluster to be the 'Nothing concerned cluster'.

Health condition of children. With respect to the health status, cluster 6 was the healthiest cluster. It had the lowest prevalence of hay fever (8.8%), rhinitis (12.7%), allergies (21.6%), eczema (9.5%) and diabetes (0.0%), and the second lowest prevalence of asthma (4.7%) and bronchitis (1.2%). Furthermore, they also had the lowest incidences of dry throat (9.4%) and dry, itchy skin (2.3%).

Preference for ICDs. Children in cluster 6 showed the least interest in the ICDs. The percentages of children who wanted to have them were all lower than average. Additionally, this cluster had the lowest percentage of children preferring a heated back (21.4%) and the second lowest percentages of children who preferred the other devices.

4. Discussion

4.1. Existing problems in classrooms studied

This study presents children's preferences and needs for IEQ conditions. First the global analysis was made among all schools, and subsequently, non-traditional and traditional schools were analysed separately because of the differences of school children's perceptions between these two types of schools [15]. Bluyssen et al. [15] reported that although the extent of complaints in the classrooms of traditional and non-traditional schools is different, all children were bothered mostly by noise (87%), followed by smells (63%). Correspondingly, in both types of schools, according to the importance indexes of environmental factors, 'hearing teacher' and 'fresh air' were considered as very important (grade higher than 7 out of 10 scores). The analysed relationships between school children's perceptions and preferences were indeed only relevant at the child level. Similarly, the relationships between children's comfort perceptions and the importance indexes of environmental factors were also more relevant at child level than at classroom level. It seems therefore that IEQ problems in classrooms are difficult to generalize, because they differ from child to child, and so do the possible solutions. Since it is impossible to study the problem-solution relationships for each child individually, a possible way to investigate these problem-solution relationships could be to group children into segments with similar preferences and needs. Eventually, profiles were developed based on the descriptive data of each of the segments.

4.2. School children's profiles

Similar to a study conducted among home occupants by Ortiz and Bluyssen [34], the two-step cluster analysis proved to be a suitable method to distinguish clusters among classroom occupants, i.e. school children, and to provide better understanding of children's characteristics, preferences and needs. It provided a six-cluster solution for the children participating in this study, based on which, the school children's profiles, including their general information, comfort perceptions, health status and preferences for ICDs, were developed.

In general, these six clusters have their own particular characteristics regards to discomfort and the importance indexes. Children of the 'Sound concerned cluster' were all bothered by noise and they rated the highest scores, among all clusters, for the 'outside sound' and 'inside sound'. Children of the 'All concerned cluster' were concerned about all items assessed in their classrooms, and they had problems in all aspects of IEQ. Children of the 'Smell and Sound concerned cluster' were concerned more about air and sound. Similar as the 'Sound concerned cluster', children in this cluster were also all bothered by noise, but in terms of the importance indexes, they rated the highest scores for 'hearing teacher', while rated the lowest scores for 'inside/outside sounds'. Besides, air quality was also a focus point for these children since they were all bothered by smell and rated the highest scores for 'fresh air' and 'air temperature'. For children of the 'Thermal and Draught cluster', draught and thermal conditions of classrooms were their concerns. All of them were bothered by draught and more than half of them, which is the highest percentage, were bothered by the thermal condition. Children of the 'Light concerned cluster' were more concerned about light. These children were prone to be bothered by artificial light and sunlight, moreover, they rated the highest score for the light on desk and board. As for children of the 'Nothing concerned cluster', they were not concerned about any items in their classrooms, and they had hardly any problems with any of the aspects of IEQ, in fact the opposite of the children of the 'All concerned cluster'.

4.3. ICDs as a solution?

Using the information and the clusters identified by this study, methods for improving IEQ of classrooms could be customized for each cluster. Children of each cluster have significant different characteristics except for one thing: all clusters have a considerable large percentage of children reporting being uncomfortable from noise and their preferences for headphones. As a general problem, noise has been the focus of studies for 40 years [40,41], but it seems that this problem needs to be tackled at both classroom and personal level, perhaps by using headphones as was pointed out by many children in the 'Sound concerned cluster'. For the children of the 'Smell and Sound concerned cluster', both noise and air were the main problems, and a ventilator was the most preferred device. Children of the 'Thermal and Draught concerned cluster' had the highest percentage of children who wanted to have a heated chair and heated back, but the lowest percentage that preferred a ventilator. For the children of the 'Light concerned cluster', both artificial and natural light, were the main problems. Nevertheless, only less than one quarter of them preferred to have a desk lamp. For

them perhaps the solution lies in the protection of sunlight, or, the possibility to control the artificial light instead of just providing them light. Future research is needed to support the insight gained in this survey in order to narrow down any possible design solutions.

The problems for the other two clusters were more complicated. Children of the 'All concerned cluster' felt uncomfortable with every aspect of IEQ and preferred all ICDs. Conversely, in the 'Nothing concerned cluster', fewer children wanted to have the proposed ICDs, they were comfort and health. Changes in the IEQ conditions of their classroom cannot make them feel more comfortable, and more studies need to be done to gain insight into these clusters to better understand their characteristics and the psychological and social impact.

4.4. Limitations

This study had two limitations: first, the sample was limited to primary school children aged between 9 and 12 years old, and most of children were from traditional schools. Also, about one third of the children's data were excluded in the two-steps cluster analysis because of the incompleteness of their questionnaires. Therefore, it is difficult to generalize for all children of primary schools. Second, the field-study was conducted from April to June, the outdoor climate could have had an impact on school children's comfort perceptions, these influences are difficult to distinguish from the influence of indoor environmental quality since only one season was considered.

5. Conclusion

The main outcome of this study is the clustering of primary school children into six profiles including their personal characteristics, health status and preferences for IEQ and ICDs, by means of two-step cluster analysis: the 'Sound concerned cluster', the 'All concerned cluster', the 'Smell and Sound concerned cluster', the 'Thermal and Draught concerned cluster', the 'Light concerned cluster', and the 'Nothing concerned cluster'. The results indicate that children do have different annoyances and different preferences related to the IEQ in classrooms. Although more research is required to complement these findings, the children's profiles might be of help in the development of children-focused design solutions and/or devices, and to further improve the IEQ of classrooms as perceived by children.

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