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# Energy consumption, self-reported teachers' actions and children's perceived indoor environmental quality of nine primary school buildings in the Netherlands

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ABSTRACT

Literature shows that both building systems and occupants' behaviour contribute to the amount of energy used to create a comfortable indoor environment. To determine possible relationships, energy consumption of nine school buildings was studied in relation to identified building characteristics, self-reported frequency of teachers' actions, and (perceived and measured) indoor environmental quality (IEQ) of the school children in the classrooms studied. These schools were located in different areas in the Netherlands, and their yearly energy consumption differed a lot. Results demonstrated significant relationships of electrical energy consumption with lighting distribution in classrooms and the frequency of teachers' light switch behaviour: the higher the measured illuminance in the classrooms, the more electricity was used in the school building. The more electricity was used, the more children complained about the IEQ in their classrooms; and the more frequently the teachers turned on the light, the less electricity the schools consumed. It was concluded that stimulating teachers to be more active in controlling the light might lead to energy saving, but a larger sample of schools with more variation in buildings systems is required to confirm this.



## 1. Introduction

Globally, energy consumed in buildings account for 20% of the total energy consumption [1], while in Europe twice as much (40%) is consumed in buildings [2]. Given the fact that global warming and the shortage of non-renewable energy becomes more and more serious, control of energy consumption is a worldwide concern. Consequently, energy consumption in buildings became a widely research topic, and several (amendments of) directives [3–6], addressing the energy performance of buildings were published by the European commission.

In terms of energy performance of buildings, a lot of emphasis has been put on the identification of the main drivers behind energy consumption in buildings [7,8]. In general, the factors that influence energy consumption can be classified into two groups: the physical-related factors and human-related factors [8]. The first group of factors include fixed physical factors, such as building characteristics (such as age, floor area, and heating and ventilation system) and climatic region, while the second group of factors include the occupant-related factors, such as occupants' behaviour and indoor environmental conditions [8,9]. In the last two decades or so, energy consumption in school buildings and its potential drivers have attracted attention. Because most studies addressing energy consumption in schools have been conducted in a specific area or country, the investigated schools often share the same the climate, which made building characteristics and occupants-related factors the main focus for these studies.

### 1.1. Energy consumption and school building characteristics

In many previous studies, the effect of building characteristics on energy consumption, such as age [10,11], floor area [8], and type of heating and ventilation system was investigated [12,13]. A large field study on energy consumption in schools in the US showed that new schools consumed more electricity than older ones [11]. A similar result was found by Ouf and Issa in Canadian schools [14]. However, for gas consumption they found the opposite: newer schools consumed less gas than the older schools [14]. What is important to note, is that several studies have shown that the relationship between energy consumption and age of buildings seems to depend on the metrics used to determine energy consumption. For example, the analysis of energy consumption in 29 schools in Italy revealed that older schools consumed less energy

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per student, while the newer schools consumed less energy per unit of volume [15]. In terms of building area, although no significant effect of building size on energy consumption per unit of area has been established, a tendency that larger buildings are more likely to consume more energy than smaller buildings was identified by Li et al. [8]. The effect of type of HVAC (heating, ventilating and air-conditioning) system on energy consumption has been investigated in many studies. It is not difficult to understand that a building with a running HVAC-system consumes more electrical energy than a building with only natural ventilation [12]. Therefore, to save energy, natural ventilation is usually considered first to be used in schools [16]. For the same reason, even though some schools have an HVAC-system, these devices are used seldom [13].

### 1.2. Energy consumption and occupants' behaviour

Occupants' behaviour in school buildings, with regard to energy consuming activities and time spent indoors, is often quite different from commercial and residential buildings [17]. Usually, the main occupants in school buildings, namely school children, cannot or are not allowed to control the available devices and systems for heating, lighting, or ventilation. While the teachers do have the authority to control these devices and systems [18], they often do not have the information and/or have little interest in the energy consumed in schools [17]. The actions teachers perform to improve indoor environmental quality (IEQ), especially the ones that consume energy (such as turning on/off heating and turning on/off light) are very likely to influence the energy consumption in school buildings. Therefore, the investigation of teacher's actions in the classrooms are important to both children's comfort in the classrooms and energy consumption in the school buildings.

### 1.3. Energy consumption and IEQ in school buildings

Next to energy consumption, an important indicator to evaluate the performance of a building is the IEQ. It is important that a school building provides a healthy and comfortable learning environment. Many studies have been conducted to investigate IEQ (i.e. thermal, air, lighting and/or acoustical quality) in classrooms of schools [19–22]. Studies focused on energy consumption and IEQ [12,13,23–25] showed that reduction of energy consumption in school buildings without compromising IEQ in classrooms is often a complex challenge but not unachievable. For example, by rescheduling building management systems [24,25] or by adjusting ventilation schemes and rates [12], both energy efficiency and IEQ in classrooms can be improved. Also, several studies on energy refurbishment of buildings found a positive effect of refurbishment on IEQ. Among the four factors of IEQ, the improvement was most often found for thermal quality [26–28], and sometimes for all four IEQs: an energy renovation project of a school building in Italy demonstrated that implementing energy saving measures could improve not only the thermal quality, but also the air, lighting and acoustical quality of the classrooms [29].

In the spring of 2017, a survey on IEQ was performed of 54 classrooms at 21 primary schools in the Netherlands [30]. All the schools were visited by a team of researchers at a preselected day to conduct a survey. The survey comprised of a questionnaire for teachers on their actions to improve IEQ, a questionnaire for children on their health, comfort and preferences, and a checklist on building and system characteristics, including also energy consumption data. All the questionnaires and checklists were distributed and collected at the same day. The main results on children's health and comfort, preferences, teachers' activities have been reported elsewhere [21,30,31]. According to the previous analyses, all the school children were dissatisfied with the IEQ in their classrooms, and noise was found to be the biggest annoyance [30]. Besides, it was found that different children have different reactions towards the same indoor environment [21], and teachers' IEQ-improving actions did not improve this [31]. In the underlying study, energy consumption was studied in relation to previously identified building and system characteristics, frequency of teachers' actions, and (perceived and measured) IEQ in classrooms.

## 2. Methods

### 2.1. Data collection

As mentioned above, this study was part of a comprehensive field study on IEQ in primary schools in the Netherlands [30]. 1145 school children and 54 teachers from 54 classrooms of 21 primary schools participated by completing a questionnaire. The children's questionnaire concerned children's symptoms (e.g. dry eyes, sneezing, difficult breathing, etc.) and complaints (e.g. thermal discomfort, draught, smell, noise, etc.) related to IEQ in their classrooms. Before the survey, the parents of all the children were informed and only the children whose parents signed the consent letter were invited to participate in the survey. The teacher's questionnaire was mainly about the frequency of actions they performed in classrooms to improve IEQ (opening/closing windows/doors, turning on/off heater/ventilation, turning on lighting, lowering/lifting shades). A short introduction on the purpose and contents was given before the children and teachers started the survey. Additionally, at least one researcher stayed in the classroom during the survey, so that questions could be asked in the case something was unclear. Additional to the questionnaires, a series of IEQ-measurements (temperature, relative humidity (RH), $CO_2$ concentration, illuminance and sound pressure level (SPL)) were conducted in the classrooms studied. All of these parameters were measured on top of a school desk by another researcher when the children and teachers were completing the questionnaires. The temperature, RH and $CO_2$ concentration were measured every 15 s by a wireless sensor kit, while the SPL was measured every 30 s by a Norsonic Nor 140 sound analyser. Moreover, all the schools and classrooms studied were inspected with the use of checklists that were completed by one researcher together with the school manager. Among the 21 primary schools, 9 provided their energy bills including the electricity and gas consumption in 2016. Therefore, the underlying study only used the data of those 9 schools (see Table1): i.e. 9 school checklists, 26 classroom checklists, 593 questionnaires completed by the children and 26 completed teachers' questionnaires.

### 2.2. Data analysis

The data analysis was conducted in three steps using SPSS version 25.0 (SPSS Inc. Chicago, IL, USA). First, descriptive analysis was performed resulting in the basic information of each of the nine school buildings with in total 26 classrooms, 26 teachers and 593 children. This information included the building characteristics, the building systems, the energy consumption in schools, the IEQ measurement results, children's IEQ-related comfort complaints, and the frequencies of teachers' actions to improve IEQ in each school. The means of teachers' activity index (TAI) and the children's personal comfort index (PCI) per school were calculated. The TAI was calculated based on teachers' individual answers with regard to how often they performed each of the 14 actions (such as opening/closing windows, putting up/down solar screen, turning on/off heating system/ventilation, etc.). There were five options for each action: more than once a day/once a day/more than once a week/once a week/less than once a week. The answers 'more than once a day' and 'once a day' were combined to 'at least once

**Table 1**
Building characteristics of the investigated schools.

| School ID* | Location | Floor area [m$^2$] | Height [m] | Age [yrs] | Floor number | Number of occupants (children and teachers) | Area per person[m$^2$] | Number of investigated classrooms/ teachers | Number of investigated children | Type of heating system | Cooling system present or not | Type of cooling system | Type of ventilation | Type of Control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5$^r$ | suburb | 1,935 | 3.4 | 90 | 3 | 429 | 13.5 | 2 | 51 | radiators or convectors | no | / | natural ventilation | / |
| 6$^r$ | suburb | 2,300 | 3.4 | 65 | 2 | 306 | 15.0 | 2 | 55 | radiators or convectors | no | / | mechanical-assisted (exhaust only) | automatic |
| 7$^r$ | rural | 1,950 | 2.8 | 52 | 1 | 436 | 4.5 | 6 | 137 | radiators or convectors | parts of the building | air conditioning cabinets | natural ventilation | / |
| 8$^r$ | suburb | 1,300 | 3.0 | 51 | 2 | 293 | 8.9 | 3 | 62 | radiators or convectors | parts of the building | air conditioning cabinets | natural ventilation | / |
| 9$^r$ | city | 1,500 | 3.0 | 89 | 2 | 169 | 17.8 | 4 | 80 | radiators or convectors | no | / | natural ventilation | / |
| 10 | suburb | 920 | 2.8 | 13 | 2 | 302 | 6.1 | 4 | 96 | radiators or convectors | no | / | mechanical-assisted (exhaust only) | automatic |
| 11$^r$ | city | 2,100 | 3.5 | 14 | 2 | 285 | 14.7 | 2 | 40 | radiators or convectors | no | / | mechanical-assisted (exhaust only) | automatic |
| 12 | suburb | 1,000 | 3.2 | 25 | 2 | 115 | 17.4 | 1 | 19 | radiators or convectors | no | / | natural ventilation | / |
| 18 | rural | 2,000 | 2.8 | 2 | 2 | 329 | 6.7 | 2 | 53 | heated floor | no | / | mechanical-balanced ventilation | $CO_2$ controlled |

**Notes:** *:the school ID is the same as in the previous paper reported on these field studies [30]; $^r$: renovated schools.

a day', and only the actions that were conducted as least once a day were counted to the TAI. Therefore, the TAI means how many actions the teacher conducted at least once a day. The PCI was calculated based on children's' individual answers with regard to their discomfort of each of the seven IEQ-factors (temperature, temperature changes, draught, smell, noise, sunlight and artificial light). First, they were asked 'Can you hear/smell/see ...in your classroom?'. If their answers were yes, then they had to answered the following questions: 'Are you bothered by the noise/smell/light ...?'. Only the affirmative answers were counted to the PCI. Therefore, the PCI shows how many IEQ-related annoyances in a classroom children were bothered with.

Second, the relationships of energy consumptions with building systems, teachers' actions, and IEQ in classrooms (both measured and perceived) were analysed. For the relationship between energy consumption and type of building system, only one type of building system, namely the type of ventilation system, was accounted for, because all schools had the same type of heating/cooling system, except for one (school 19). An independent *t*-test was used to compare the energy consumption of natural ventilated and mechanical ventilated school buildings. For the teachers' actions, first, a Pearson correlation analysis was conducted to identify the relationship between the TAI and energy consumptions in schools, then, several Spearman correlation analyses were conducted to identify the relationships between the frequencies of each action took by the teachers and the energy consumptions. For the IEQ in a classroom, a series of Pearson correlation analyses was used to determine possible relationships of energy consumptions with the measured IEQ, the overall IEQ complaints (namely PCI)/, and the percentages of children complaining about each IEQ factors in classrooms.

Finally, the nine school buildings were divided into three groups based on their energy consumption: high/medium/low-energy consuming schools, and the characteristics of the buildings in each group were analysed and summarized.

## 3. Results

### 3.1. Descriptive analysis

The nine school buildings studied comprised of a wide variety of building and system characteristics. Some of them are presented in Table 1. About half of the schools (five out of nine) were located in a suburban area, 22% (two out of nine) were located in a rural area and the rest (22%) was located in a city centre. The floor area of almost all of these schools ranged from 920 to 2,300 m$^2$ (with an average of 1,567 m$^2$) and their mean age was 45 years (ranging from 2 to 90 years). Three (33%) of these buildings were younger than 20 years, while three (33%) were older than 60 years. Most schools (seven out of nine) occupied two floors; one school occupied a single floor; and one occupied three floors. The height of these nine buildings were within a range between 2.8 and 3.5 m, with an average height of 3.1 m. All schools, except one (school 19), used a radiator for heating. Most of the schools did not have a cooling system, only parts of schools 7 and 8 used air conditioning units for cooling. In terms of ventilation, most schools had natural ventilation or mechanical-assisted ventilation (exhaust only), only one school (school 19) had $CO_2$ controlled mechanical-balanced ventilation.

The energy consumption for electricity and gas is presented in Table 2 for each of the nine schools studied. The results show a wide range: the electricity consumption varied from 252,000 to 570,431 MJ, with an average value of 179,466 MJ, and the gas consumption varied from 84,656 to 2,370,849 MJ, with an average value of 943,385 MJ. Among the investigated schools, school 10

**Table 2**
The energy consumption in the investigated schools in one year.

| School ID* | Electricity consumption [MJ] | Gas consumption [MJ] | Electricity consumption per unit of area [MJ/m$^2$] | Gas consumption per unit of area [MJ/m$^2$] |
|---|---|---|---|---|
| 5 | 112,018 | 885,965 | 19.3 | 152.6 |
| 6 | 25,200 | 636,400 | 5.5 | 138.3 |
| 7 | 179,348 | 562,400 | 92.0 | 288.4 |
| 8 | 115,200 | 2,146,000 | 44.3 | 825.4 |
| 9 | 95,400 | 623,228 | 31.8 | 207.7 |
| 10 | 570,431 | 2,370,849 | 310.0 | 1288.5 |
| 11 | 184,802 | 786,287 | 44.0 | 187.2 |
| 12 | 66,794 | 84,656 | 33.4 | 42.3 |
| 18 | 266,004 | 394,679 | 66.5 | 98.7 |
| Average | 179,466 | 943,385 | 71.9 | 358.8 |
| S.D. | 163,022 | 782,008 | 92.8 | 418.1 |

**Note:** *: the school ID is the same as in the previous paper reported on these field studies [30].

consumed the most energy, regarding both electricity and gas; while school 6 consumed the least electricity and school 12 consumed the least gas in 2016.

The distribution of teachers' TAI of each school was calculated and presented in Fig. 1. The mean TAI of the nine schools was 9.9, which means that on average, primary school teachers performed approximately 10 actions at least once a day. Considering the median values, the maximum appeared in school 11 (12.5), while the minimum appeared in schools 7, 8, and 18 (8.0). Besides the TAI, five specific energy-consuming actions (namely, turning on/off heaters, turning on/off cooling/ventilation, and turning on light) were analysed. As shown in Fig. 2, in school 9 and school 11, the frequencies of all these actions were above the median value 3. While in school 18, the frequencies of these actions were below the median value, consistent with the results of the distribution of TAI shown in Fig. 1. This means that teachers in schools 9 and 11 conducted all of these actions at least once a day, while teachers in school 18 conducted these actions less than once a day. In the rest of the schools, some actions were conducted by the teachers more often, while other actions were conducted rarely.

During the field study, several measurements including lighting level at the desk, air temperature, RH, $CO_2$, and SPL were conducted in the classrooms studied. As shown in Table 3, the lighting level and $CO_2$ values differed considerably, while the air temperature, RH and SPL values were rather consistent. In terms of the related requirements, all the schools could meet the thermal requirement of the ASHRAE standard [32]. However, according to the Dutch fresh school guidelines on IEQ [33], the $CO_2$ levels in classrooms of schools 5, 6, and 9 exceeded the requirement for the lowest level (1200 ppm), and only schools 5, 10, and 11 could meet the minimum requirement of illuminance (300 Lux). Additionally, the SPLs in all of these schools were too high and far exceeded the recommended level [34]. This confirmed the finding of the previous study that noise is the biggest problem in Dutch primary schools [30].

Additionally, children's IEQ perceptions were collected, analysed and summarized into the PCI for each child. The PCI is defined as the number of complaints a child had out of 7 possible complaints (thermal discomfort, temperature changes, wind/draught, smells, noise, sunlight and artificial light) [30]. The distribution of PCI for all participating children per school was calculated and is presented in Fig. 1. The distribution of PCI of the children in these schools did not show significant fluctuations. The maximum and minimum results were 3.5 in school 10 and 2.1 in school 11, respectively, and the average result was 2.7, which means that on average the participated children were bothered by around 3 indoor environmental factors in their classrooms.

To identify the specific IEQ-related annoyance in the different schools, the percentages of children who reported being bothered by the seven IEQ- factors in each school were calculated. As shown in Fig. 3, children were bothered the most by noise, while with draught and artificial light they were the least bothered. This confirmed the results found in the previous study [30]. Additionally, several of the highest values (e.g. thermal uncomfortable, sunlight, and artificial light) are seen in school 10, while some of the lowest values appeared in school 11 (e.g. thermal uncomfortable, temperature change, and noise). This finding is in line with the results of the average PCIs shown in Fig. 1.

### 3.2. Energy consumption and building characteristics

The data analysis resulted in no statistically relationships between energy consumptions and building characteristics of the investigated school buildings. However, a tendency of a negative relationship still can be seen between the energy consumptions and the age and floor area of the investigated buildings (see Table 4.

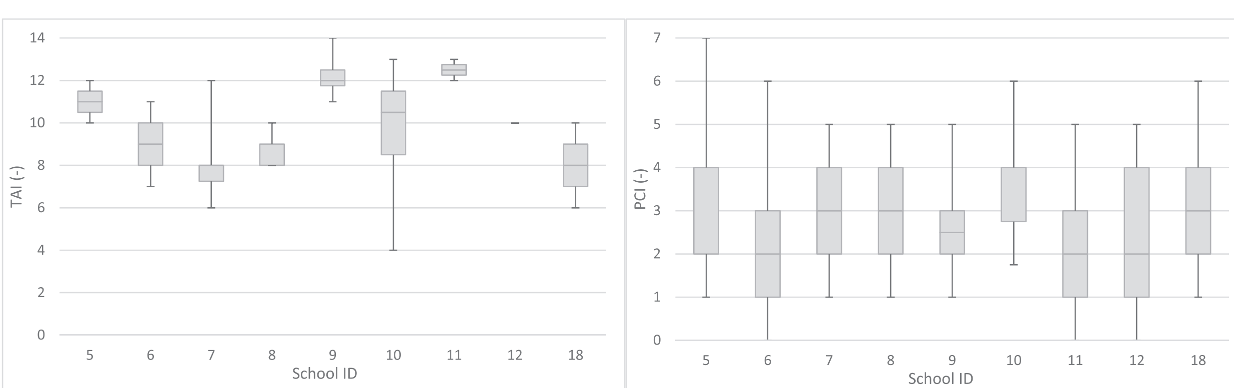


**Fig. 1.** The average TAI and PCI in the nine schools (**Note:** the school ID is the same as in the previous paper reported on these field studies [30]).

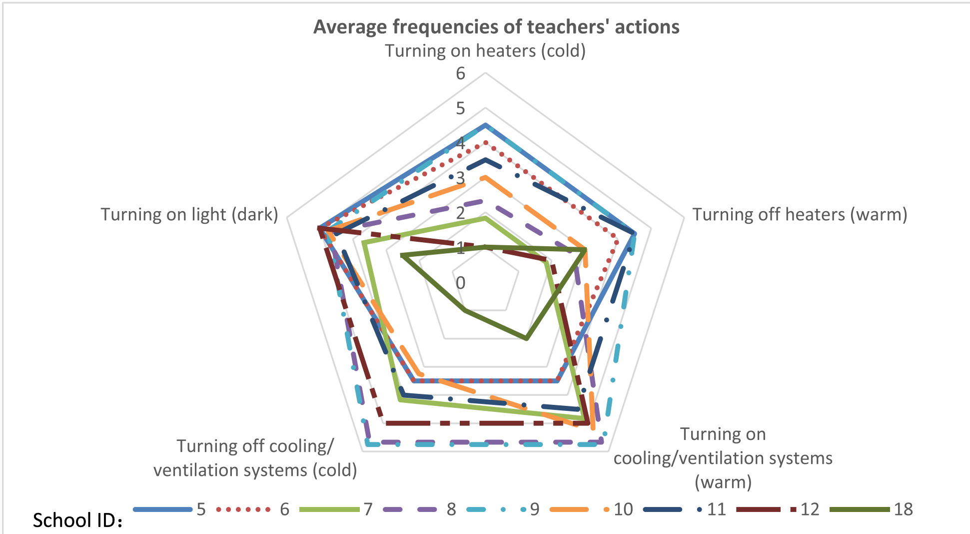


**Fig. 2.** The frequency of energy consuming actions that were conducted by teachers. **Notes:** 1 means less than once a week; 2 means once a week; 3 means less than once a day; 4 means once a day; 5 means more than once a day; the school ID is the same as in the previous paper reported on these field studies [30].

**Table 3**
The average values of measurement results in the investigated schools.

| School ID* | Temperature [℃] | Relative Humidity [%] | $CO_2$ [ppm] | Lighting level [Lux] | SPL [dB (A)] |
|---|---|---|---|---|---|
| 5 | 22 (0) | 35 (0) | 1917 (118) | 314 (340) | 104 (3) |
| 6 | 21 (1) | 33 (0) | 1226 (31) | 168 (83) | 102 (0) |
| 7 | 23 (1) | 46 (1) | 1169 (88) | 82 (16) | 102 (1) |
| 8 | 23 (2) | 44 (4) | 1031 (531) | 197 (105) | 102 (2) |
| 9 | 23 (1) | 46 (2) | 1670 (660) | 99 (58) | 102 (0) |
| 10 | 24 (3) | 47 (5) | 1066 (79) | 823 (1107) | 104 (3) |
| 11 | 22 (1) | 40 (2) | 1065 (27) | 518 (469) | 102 (0) |
| 12 | 24 (–) | 36 (–) | 1060 (–) | 118 (–) | 101 (–) |
| 18 | 24 (1) | 36 (4) | 792 (121) | 179 (101) | 102 (1) |
| Average | 23 (1) | 41 (6) | 1260 (462) | 255 (364) | 102 (1) |

**Note:** ***:** the school ID is the same as in the previous paper reported on these field studies [30].

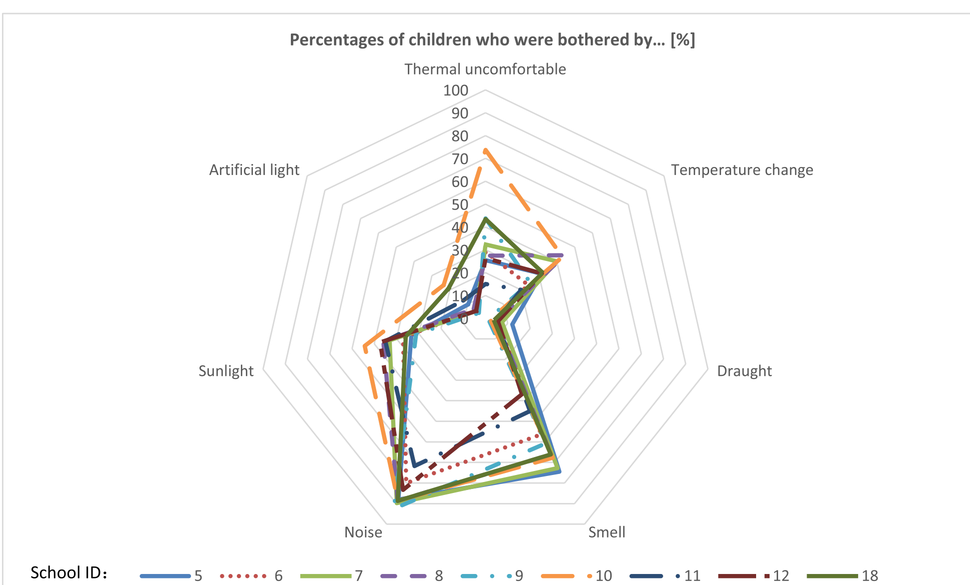


**Fig. 3.** IEQ-factors in the nine schools (**Note:** the school ID is the same as in the previous paper reported on these field studies [30]).

The energy consumptions (both electricity and gas consumption) in older schools, such as schools 5, 6 and 9, were relatively lower than in the other schools. In terms of the building size, the building with the smallest floor area, namely school 10, consumed much more energy per $m^2$, while the building with the largest floor area, namely school 6, consumed much less energy per $m^2$ than the

**Table 4**
Relationship between energy consumptions and building age and floor area.

| | | Electricity consumption ($MJ/m^2$) | Gas consumption ($MJ/m^2$) |
|---|---|---|---|
| Age | Pearson Correlation | −0.460 | −0.228 |
| | P-values | 0.213 | 0.556 |
| Floor area | Pearson Correlation | −0.536 | −0.598 |
| | P-values | 0.137 | 0.089 |

**Notes**: P-values are obtained from Pearson correlation analysis.

other schools. While the independent *t*-test did not show any statistically significant differences of energy consumption between the renovated and non-renovated buildings, nor between natural and mechanical ventilated buildings (see Table 5). However, if only the mean levels of these buildings are considered, the renovated buildings consumed much less energy (both electricity and gas) than the non-renovated buildings; and the mechanical ventilated buildings consumed more energy than the natural ventilated buildings, especially with regards to electricity.

Concerning the teacher's actions, as shown in Table 6, no statistically significant relationships were found between the TAI and energy consumptions ($p > 0.05$). Nevertheless, a tendency for a possible relationship can be seen in Fig. 4: in the school that consumed the most energy (e.g. school 10, 7, and 18), the teacher's TAI was relatively low. To further investigate the possible impact of energy consumed actions conducted by teachers on school energy consumptions, several correlation analyses were conducted separately for each of the actions. As shown in Table 5, almost no statistically significant relationship was found between these actions and energy consumptions, except for one action: turning on the light. A statistically significant negative relationship was found between the frequency of turning on the light and the yearly total electricity consumption. It showed that when the teachers turned on the light more often, less electricity was consumed.

Significant relationships were found for the illuminance measured in the classrooms and the yearly energy consumption (Table 7). For electricity consumption: $\gamma = 0.773; p = 0.015$; for gas consumption: $\gamma = 0.686; p = 0.041$. In a school with a high illuminance, the energy consumption was found to be high as well. For the relationships between the other indoor environmental parameters and energy consumptions, no statistically significant relationships were found.

In terms of the children's perceived IEQ or their PCI, a statistically significant relationship was found for the average PCI and electricity consumption of schools ($\gamma = 0.813; p = 0.008$). In the school that consumed more electricity, the children reported more complaints about IEQ in their classrooms (see Fig. 5). A similar relationship was found between the PCI and gas consumption ($\gamma = 0.761; p = 0.017$).

Next to the average PCI, the relationship between each of the different IEQ complaints and the energy consumption in schools was analysed. As shown in Table 8, the electricity consumption in schools was found to be significantly related with children' complaints about thermal comfort ($\gamma = 0.852; p = 0.004$), sunlight ($\gamma = 0.678; p = 0.045$), and artificial light ($\gamma = 0.707; p = 0.033$). Additionally, gas consumption was found to be significantly related with children's complaints about thermal comfort ($\gamma = 0.678; p = 0.045$), temperature changes ($\gamma = 0.715; p = 0.030$), and sunlight ($\gamma = 0.676; p = 0.046$). All relationships were positive, which means that the more electricity the school consumed, the more complaints about thermal comfortable, sunlight and artificial light were reported by the children. And the more gas was consumed, the more complaints were reported on thermal comfort, temperature changes and sunlight.

**Table 6**
Relationships between the energy consumptions and the TAI.

| | | Electricity consumption ($MJ/m^2$) | Gas consumption ($MJ/m^2$) |
|---|---|---|---|
| TAI | Pearson Correlation | −0.205 | −0.211 |
| | P-values [a] | 0.596 | 0.586 |
| Turn on heater | Correlation coefficient | −0.605 | 0.227 |
| | P-values [b] | 0.084 | 0.557 |
| Turn off heater | Correlation coefficient | −0.562 | −0.077 |
| | P-values [b] | 0.115 | 0.845 |
| Turn on cooling/ ventilation | Correlation coefficient | 0.393 | 0.428 |
| | P-values [b] | 0.295 | 0.250 |
| Turn off cooling/ ventilation | Correlation coefficient | 0.086 | 0.242 |
| | P-values [b] | 0.825 | 0.531 |
| Turn on light | Correlation coefficient | -0.698* | −0.264 |
| | P-values [b] | **0.037** | 0.493 |

**Notes**: a. P-values are obtained from Pearson correlation analysis; b. P-values are obtained from Spearman correlation analysis; P-values in bold mean statistically significant at the 5% level; * means significant correlation at the 0.05 level (2-tailed).

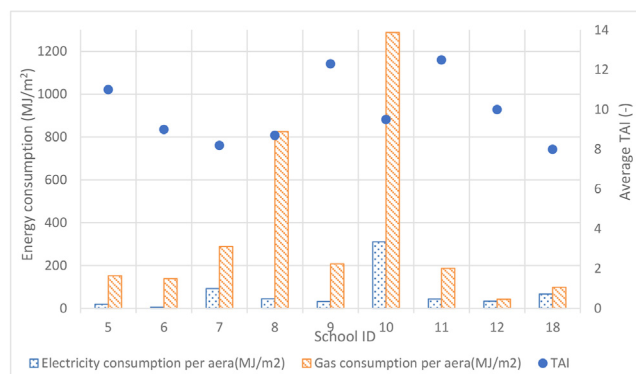


**Fig. 4.** The average TAI in the investigated schools (**Note:** the school ID is the same as in the previous paper reported on these field studies [30]).

**Table 5**
Difference of energy consumptions between buildings with different types of ventilation systems and between renovated and non-renovated buildings.

| Energy & Renovation | Renovated (Mean) | Non-renovated (Mean) | T | P-values |
|---|---|---|---|---|
| Electricity consumption ($MJ/m^2$) | 11.0 | 38.0 | $t_{2.1} = 1.105$ | 0.381 |
| Gas consumption ($MJ/m^2$) | 8.1 | 12.9 | $t_{2.3} = 0.420$ | 0.711 |
| **Energy & Ventilation** | Natural (Mean) | Mechanical (Mean) | t | P-values |
| Electricity consumption ($MJ/m^2$) | 122.8 | 238.3 | $t_{3.2} = 1.001$ | 0.350 |
| Gas consumption ($MJ/m^2$) | 81.8 | 93. 8 | $t_7 = 0.422$ | 0.686 |

**Note**: P-values are obtained from t-tests.

**Table 7**
Relationship between energy consumption and IEQ-measurements.

| | | Electricity consumption (MJ/m$^2$) | Gas consumption (MJ/m$^2$) |
|---|---|---|---|
| Temperature | Pearson Correlation | 0.516 | 0.303 |
| | P-values | 0.155 | 0.428 |
| RH | Pearson Correlation | 0.583 | 0.641 |
| | P-values | 0.100 | 0.063 |
| $CO_2$ | Pearson Correlation | −0.287 | −0.215 |
| | P-values | 0.453 | 0.578 |
| Illuminance | Pearson Correlation | 0.773* | 0.686* |
| | P-values | **0.015** | **0.041** |
| SPL | Pearson Correlation | 0.355 | 0.407 |
| | P-values | 0.349 | 0.277 |

**Notes**: P-values are obtained from Pearson correlation analysis; P-values in bold mean statistically significant at the 5% level; * means significant correlation at the 0.05 level (2-tailed).

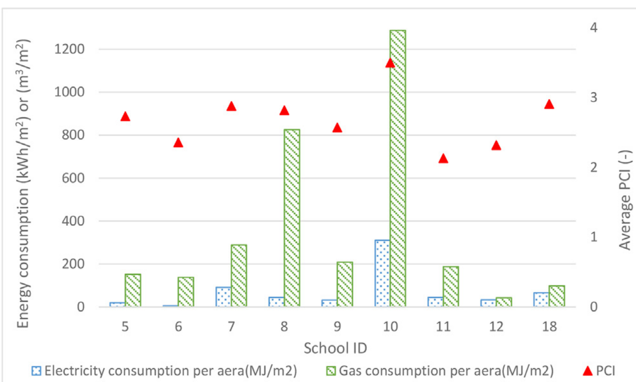


**Fig. 5.** The average PCI in the investigated schools (**Note:** the school ID is the same as in the previous paper reported on these field studies [30]).

### 3.3. Characteristics of school buildings within different energy performing levels

Fig. 6 shows the annual energy consumption (including electricity and gas consumption) per school. The results indicate that in terms of the energy consumption per area, schools 10, 8, 7 were the first three high-energy consuming schools with more than 300 MJ/m$^2$ energy consumed per year, while schools 18, 6, 12 were the three relatively low-energy consuming schools with less than 160 MJ/m$^2$ energy consumed per year. The other schools (ID: 9, 11, 5) had the middle level with the energy consumptions between 160 and 300 MJ/m$^2$ per year.

The characteristics of the three groups of schools with different energy consumption levels are presented in Table 9. In terms of the energy consumption, according the ANOVA analyses, only the gas consumption was found to be significantly different among these three groups ($F_{(2,6)} = 5.281; p = 0.048$). Also, a tendency of decline can be seen in the total energy consumption ($F_{(2,6)} = 4.845; p = 0.056$). The high-energy consuming schools spent much more energy (both the gas and the total energy) than the other two groups of schools, while the difference in energy consumption between the other two groups was small.

With regards to the building characteristics, no significant differences were found among these three groups. Based on the mean values, the in between-energy consuming schools were the oldest and covered the largest floor area, the low-energy consuming schools were the youngest and had the least occupants, and the high-energy consuming schools covered the smallest floor area and had the most occupants. Regarding the type of ventilation systems, the three groups of schools showed similar distributions.

**Table 8**
Relationships between energy consumption and children's IEQ perceptions.

| | | Electricity consumption (MJ/m$^2$) | Gas consumption (MJ/m$^2$) |
|---|---|---|---|
| **PCI** | Pearson Correlation | 0.813** | 0.761* |
| | P-values | **0.008** | **0.017** |
| **Thermal uncomfortable** | Pearson Correlation | 0.852** | 0.678* |
| | P-values | **0.004** | **0.045** |
| Bothered by **temperature changes** | Pearson Correlation | 0.575 | 0.715* |
| | P-values | 0.105 | **0.030** |
| Bothered by **draught** | Pearson Correlation | −0.390 | −0.366 |
| | P-values | 0.299 | 0.332 |
| Bothered by **smell** | Pearson Correlation | 0.282 | 0.358 |
| | P-values | 0.463 | 0.344 |
| Bothered by **noise** | Pearson Correlation | 0.235 | 0.274 |
| | P-values | 0.542 | 0.475 |
| Bothered by **sunlight** | Pearson Correlation | 0.678* | 0.0676* |
| | P-values | **0.045** | **0.046** |
| Bothered by **artificial light** | Pearson Correlation | 0.707* | 0.473 |
| | P-values | **0.033** | 0.198 |

**Notes**: P-values are obtained from Pearson correlation analysis; P-values in bold highlighted are the correlations with statistical significance ($p < 0.05$); *, correlation is significant at the 0.05 level (2-tailed);
**, correlation is significant at the 0.01 level (2-tailed).

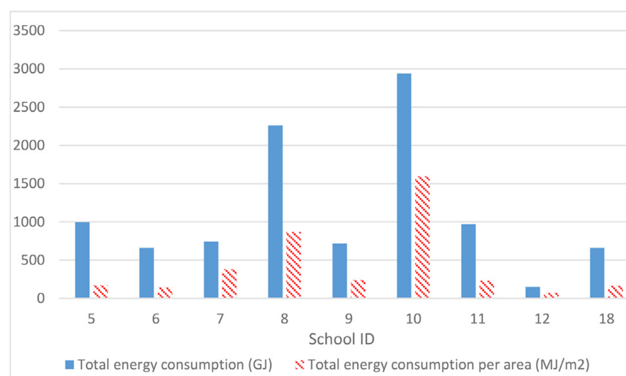


**Fig. 6.** Total energy consumption of the nine schools (**Note:** the school ID is the same as in the previous paper reported on these field studies [30]).

For the measured IEQ in classrooms, only the RH was found to be significantly different among these three groups ($F_{(2,6)} = 6.901; p = 0.028$), the high-energy consuming schools had the highest RH and the low-energy consuming schools had the lowest RH. For the other variables, according to the mean values, the highest illuminance appeared in the high-energy consuming schools; and the highest $CO_2$ level appeared in the in between-energy consuming schools. Furthermore, almost no difference of temperature and sound level was found between these groups of schools.

For the children's IEQ perceptions, only the percentage of children who complained about temperature changes was found to be significantly different among these three groups

**Table 9**
Characteristics of schools with different energy consumption levels.

| | High-energy consuming schools (ID: 10, 8, 7) | In between-energy consuming schools (ID: 9, 11, 5) | Low-energy consuming schools (ID: 18, 6, 12) |
|---|---|---|---|
| *Energy consumption* | | | |
| Total [MJ/m$^2$] | **187.4** (119.9) | 96.0 (33.4) | 65.8 (6.5) |
| Electricity [MJ/m$^2$] | **148.8** (141.7) | 31.7 (12.4) | 35.1 (30.5) |
| Gas* [MJ/m$^2$] | **800.8** (500.5) | 182.5 (27.9) | 93.1 (48.3) |
| *Building characteristics* | | | |
| Age [yrs] | 38.7 (22.2) | **64.3** (43.6) | 30.7 (31.9) |
| Floor area [m$^2$] | 1390.0 (520.9) | **1845.0** (310.0) | 1766.7 (680.7) |
| Occupants [–] | **343.7** (80.1) | 294.3 (130.3) | 250.0 (117.5) |
| Ventilation systems [–] | Mixed (two natural and one mechanical assisted) | Mixed (two mechanical assisted and one natural) | Mixed (two natural and one mechanical balanced) |
| *Averaged measured IEQ* | | | |
| Temperature [℃] | **23.4** (0.8) | 22.4 (1.0) | 23.3 (1.7) |
| RH* [%] | **45.7** (1.8) | 40.2 (5.6) | 34.9 (1.9) |
| $CO_2$ | 1088.4 (71.8) | **1550.3** (438.4) | 1026.0 (218.7) |
| Illuminance [Lux] | **367.5** (398.6) | 310.5 (209.5) | 155.0 (32.3) |
| SPL [dB (A)] | 102.6 (0.9) | **102.9** (1.3) | 101.7 (0.8) |
| *Children's IEQ perception* | | | |
| PCI [–] | **3.1** (0.4) | 2.5 (0.3) | 2.5 (0.3) |
| Bothered by thermal uncomfortable [%] | **44.5** (25.4) | 28.1 (14.5) | 32.9 (9.2) |
| Bothered by temperature changes* [%] | **42.5** (2.2) | 25.5 (5.7) | 29.1 (4.7) |
| Bothered by draught [%] | 4.8 (2.7) | **6.1** (3.1) | 5.0 (1.0) |
| Bothered by smell [%] | **68.9** (3.5) | 60.1 (14.8) | 53.1 (14.9) |
| Bothered by noise [%] | **89.0** (0.6) | 84.1 (10.9) | 84.0 (4.4) |
| Bothered by sunlight [%] | **47.8** (5.8) | 36.5 (7.4) | 40.1 (6.4) |
| Bothered by artificial light [%] | **11.7** (10.2) | 8.7 (4.5) | 10.5 (8.9) |
| *Teachers' actions* | | | |
| TAI* [–] | 8.8 (0.7) | **11.9** (0.8) | 9.0 (1.0) |
| Turn on heater [–] | 2.4 (0.6) | **4.2** (0.6) | 2.0 (1.7) |
| Turn off heater* [–] | 2.5 (0.6) | **4.5** (0.0) | 3.0 (1.0) |
| Turn on cooling/ventilation [–] | **4.8** (0.4) | 3.5 (2.2) | 2.7 (2.1) |
| Turn off cooling/ventilation [–] | **3.5** (1.4) | 3.3 (2.1) | 2.3 (2.3) |
| Turn of light [–] | 4.4 (0.6) | **4.8** (0.3) | 4.2 (1.4) |

**Note**: * means that the variables were significantly different among the three groups based on the results of ANOVA ($p < 0.05$); the values in bold are the maximum values.

($F_{(2,6)} = 11.994; p = 0.008$). The highest percentage appeared in the high-energy consuming schools, while the lowest percentage appeared in the in between-energy consuming schools. According to the mean values, children's average PCI was highest in the high-energy consuming schools: in these schools, the highest percentages of children that complained about all of the investigated IEQ factors in their classrooms, except for draught, were identified.

For the teachers' actions, the TAI was found to be significantly different among the three groups of schools ($F_{(2,6)} = 7.14; p = 0.026$). The teachers in the in between-energy consuming schools were the most active (with the highest TAI), while the teachers in the high-energy consuming schools were the least active (with the lowest TAI). The same was found for the frequency of turning off heaters by teachers ($F_{(2,6)} = 13.229; p = 0.006$). The mean values of the frequencies of other actions conducted by teachers indicated that the teachers in the in between-energy consuming schools turned on heaters and lights most frequently, while in the high-energy consuming schools, the teachers turned on/off the cooling/ventilators most frequently.

## 4. Discussion

### 4.1. Do building characteristics related to energy consumption?

From the analysis of the current dataset, no statistical relevant relationship between building characteristics and energy consumption in the investigated schools could be found. This, however, does not mean there is no relation. Due to the small sample size, the possibility of committing type Ⅱ error in the statistical tests is clearly present. This means that there might be a relationship between the tested variables, but because of the small sample size it was misinterpreted as no relationship [35].

Nevertheless, the collected data indicate several tendencies for relationships between energy consumption and building characteristics. In terms of age, it was found that the older schools consumed relatively less electricity and gas per m$^2$, partly confirming results found in previous studies [11,14], in which new schools consumed more electricity. However, the study reported by Ouf and Issa [14] also demonstrated that new schools consumed less gas, which is just the opposite of the results found in the present study. A possible reason for this inconformity could be that in the present study some of the old schools were renovated, which resulted in a decrease of energy consumption.

This study showed that small school buildings were more likely to consume more energy per m$^2$ and large school buildings seem to consume less, while in previous studies on office buildings the reverse was seen [8,9]. The difference in energy consumptions of offices with different sizes was attributed to the operation and maintenance of offices: small offices that usually just had simple functions and regular schedules are easier to manage than multi-functional large office buildings [8,9]. Because all school buildings studied had the same function, and primary schools are usually not large buildings, such a comparison could not be made.

That no statistical differences between energy consumption in natural ventilated schools and mechanical ventilated schools was found, might be related to the sample size: only two of the investigated schools had mechanical ventilation. However, the mean value of the electricity consumption in mechanical ventilated schools was almost twice than that of the natural ventilated schools. This outcome confirms results of several previous studies in which mechanical ventilated buildings consumed more electricity than natural ventilated buildings [8,16]. It might also be the reason why natural ventilation is so popular at Dutch schools.

### 4.2. Do teachers actions relate to energy consumption?

In general, the results of the correlation analysis showed no statistically significant relationship between teachers' activity level (or TAI) and energy consumption of schools. As pointed out above, this might be related to the small sample size. Nevertheless, the data showed that at schools with teachers who had high activity levels (high TAI), less energy was consumed than at schools with teachers who had low TAIs. One possible explanation might be that if the teacher was more active, she/he would perform a switch action to the light, heating, and cooling devices more frequently. This could indicate that the energy-consuming devices were only used when it was necessary. Conversely, if the teachers were not active, then, as shown in Fig. 4, the energy consumptions of the schools were higher.

The detailed analyses between teachers' specific actions and energy consumption in schools indicated that only the frequency of turning on the lights was found to be significantly related to energy consumptions. The more often the teacher turned on the lights, the less energy was consumed. This might be related to the fact that unlike cooling/heating systems, lights are the basic energy consuming equipment in all Dutch primary schools and they were used almost every day. Moreover, a previous study showed that lighting, as the biggest electricity consumer, accounted for 28% of all energy consumption in a school, which was much higher than ventilation (11%) or heating (9%) [36]. Therefore, it makes sense that the teachers' light switch action was more related with energy consumption than the heater and ventilation switch actions. The negative relationship between the frequency of turning on the light and energy consumption also could be explained by the possibility mentioned above: that more often switching lights could assure that lights are used only when necessary, so more energy is saved. A similar result was found by Hong and Nord [9], who investigated the occupant switching on/off lighting behaviour in two office buildings. They found that the office where occupants could adjust lights according to outdoor lighting conditions consumed less energy than the office where the light use was always the same despite the outdoor lighting conditions.

### 4.3. Does IEQ relate to energy consumption?

With regards to the measured IEQ parameters in the classrooms, similar as with the teachers' actions, only the light-related variable, the illuminance, was found to be related with energy consumption. The higher measured illuminance in the classrooms, the more energy the schools consumed. As mentioned before, lighting was the major part of the total energy consumption in several studies on schools [36,37], and it has shown considerable energy saving potential in other studies [38,39]. Therefore, to improve both energy efficiency and IEQ in classrooms, many lighting-related strategies, such as using daylight, selecting a more efficient lighting system, and using digital/automatic lighting controls, have been put forward by previous studies [25,36,40]. Compared with these methods, improving teachers' energy-saving awareness and guide their actions by a more rational use of artificial light and daylight might be the easiest and the cheapest method to implement, since teachers' lighting-related behaviour was also found to be significantly related with energy consumption of schools.

In terms of children's IEQ perception, it was identified that the more energy the schools consumed, the more children felt uncomfortable about the IEQ, especially with the thermal and light conditions in their classrooms. Although no causational relationship between children's perceived IEQ and the energy consumption in schools can be deduced from this result, it at least demonstrates that saving energy and improving IEQ were not contradictory.

### 4.4. Clustering of primary schools based on their total energy consumption

Because of the limited amount of school buildings, cluster analysis was not suitable for this study. Therefore, the schools were manually classified based on their total energy consumptions. Regarding the building characteristics, there is no big differences among these three groups of schools. One thing should be noted is that the mean age of the in between-energy consuming schools were relatively older than the other groups, however, these older schools were all renovated in the last two decades.

With regards to the measured IEQ in the classrooms, the high-energy consuming schools appeared to be slightly better than the other schools. The three schools of this cluster all met the thermal and air quality recommendations as given in the Dutch fresh school guidelines [33]. However, similar to the other two groups of schools, some high-energy consuming schools did not meet the lighting recommendations and none of them met the recommendation for acoustics.

In terms of IEQ in classrooms and teachers' actions, it was found that the children in the in between-energy consumption schools complained relatively less, especially on thermal and lighting conditions in their classrooms, while the teachers in these school preformed IEQ-improving actions more often. It must be noted that although these schools were named in between-energy consuming schools, their energy consumptions were much lower than the average level of the investigated schools, and their mean electricity consumed was even lower than the low-energy consuming schools. In fact, compared to the high-energy consuming schools, these in between energy consuming schools not only had a better perceived IEQ in their classrooms but also saved more energy.

### 4.5. Limitations and future studies

This preliminary investigation of relationships between energy consumptions and IEQ in Dutch primary schools has two major limitations. The first limitation concerns the sample size, only nine schools were included in the study, which might be insufficient to identify significant relationships from this data. The second limitation is that only the annual energy consumptions in schools were recorded and collected, so, it was difficult to recognize the differences between heating season and non-heating season or between school days and holidays. For future studies it is recommended to include more schools, more children, and collect more detailed data (e.g., monthly energy consumptions) to better pinpoint possible relationships.

## 5. Conclusion

This study investigated the energy consumption of nine Dutch primary schools, and its relationships with school building characteristics, teachers' actions, and (IEQ in classrooms. The statistically significant relationship found between the measured illuminance in the classrooms and energy consumption in the schools might indicate a possible way to save energy through light control. Moreover, the statistically significant relationships between teacher's actions and energy consumptions in schools implied that guiding teachers' actions for a rational use of energy, especially the artificial light, might provide a simple and feasible way to save energy. Additionally, this study clustered the investigated schools into three groups based on their energy consumptions. A comparison of the groups showed that the in between-energy consuming schools used the least electrical energy and at the same time maintained the best perceived IEQ in classrooms (children in these schools complained about at least for four out of seven IEQ factors), indicating that comfort and reduction of energy consumption can go together. A larger sample with more variation in systems characteristics as well as more detailed data collection (e.g. energy consumption per month; perception in different seasons), is recommended.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2021.110735.

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