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The role of flooring materials in health, comfort and performance of children in classrooms

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Abstract: From previous and recent studies, it is clear that an indoor environment of a school may affect the health, comfort and performance of schoolchildren. Besides the occupants and their activities, the windows and the outdoor environment and the type of ventilation system, the interior (furnishing incl. flooring materials) is an important contributor to that indoor environment quality. It seems that flooring materials (having the largest surface area) are able to effect indoor air, acoustical, lighting and thermal quality. This paper focuses on the role of flooring materials in health, comfort and performance of children in classrooms, what do we know and which directions of research are needed.

Subjects: Environmental Studies & Management; Physical Sciences; Built Environment

Keywords: classroom; indoor environment quality; flooring materials; children; health; comfort; performance

1. Introduction

Except for at home, children spend more time in schools than in any other place. Children are more susceptible than adults to effects of toxic exposure and to poor acoustic conditions. Unsatisfactory environmental conditions in classrooms, can have both short-term and long-term health effects,

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Prof. Dr Philomena M. Bluyssen was appointed as a full Professor of Indoor Environment in 2012. The focus of her research is people and their health and comfort, influenced by buildings and environmental factors, indoors and outdoors. Key is the assessment and control of the effect of the combination of environmental parameters (thermal, acoustical, lighting and air quality) on people and the built environment, in order to turn the negative effect around into a positive experience. She created “The Senselab”, a playground for the senses, in which single and combinations of environmental conditions in different scenarios (offices, schools) can be both experienced and tested. One of her many publications is the “Indoor Environment Handbook: How to make buildings healthy and comfortable”, which received the “Choice Outstanding Academic Titles Award 2010”. “The Healthy Indoor Environment: How to assess occupants” wellbeing in buildings' was awarded the Interior Design Educators Council (IDEC) 2016 book award.

PUBLIC INTEREST STATEMENT

It is clear that indoor environmental conditions affect health, comfort and learning performance of schoolchildren, but also that the behaviour and activities performed by the students influence the environmental conditions. Even though flooring materials (having the largest surface area) are able to effect indoor air, acoustical, lighting and thermal quality, not many studies have considered flooring materials as a primary topic of research. To get more insight in the current and potential role of flooring materials on health, comfort and performance of children there is a clear need for a holistic analysis of classrooms and student performance, in real-life and semi-lab situations (for example in the Senselab), in which flooring materials are considered as a potential contributor to IEQ, including classrooms with different space and systems configurations (e.g. heating, lighting, ventilation, educational setting and interior furnishings), environmental factors and other aspects (e.g. confounders).

and can affect productivity or learning ability of the children. Many studies all over the world have been performed, in the last decades, to document the indoor environment in classrooms and to examine relations with diseases and disorders.

From a literature study on (inter)national studies performed in and/or with children from primary (elementary) and secondary (high) schools, focused on the four factors of indoor environmental quality (IEQ) (indoor air, thermal, acoustical and lighting quality) and the effects on children is clear that an indoor environment of a school, may affect the health, comfort and performance of school-children (Bluyssen, 2016). The indoor environment quality of a classroom seems to be determined by its occupants (mainly the children) and their activities, the interior (furnishing incl. flooring materials), the windows and the outdoor environment, and the type of ventilation system.

Many different flooring materials are available these days. They comprise numerous different materials and substances, which can influence indoor environmental factors differently, but also vice versa. Because of their large surface areas, flooring materials are important potential contributors to the environmental quality in indoor spaces, from indoor air, acoustical, lighting and thermal quality point of view. But what do we know so far on the effect of different flooring materials on health, comfort and performance of children? This paper focuses on the role of flooring materials in health, comfort and performance of children in classrooms: what do(n't) we know and what is needed to be able to determine which flooring type is best suitable under which circumstances?

2. What do we know about flooring materials and IEQ?

To answer this question, for each of the environmental factors, it is hypothesized what the contribution could be, and, which proof has been found in previous studies of the effects of these contributions on health, comfort and performance of school children in classrooms. The discussed phenomena are presented in Table 1.

3. Air quality

As any other furnishing material in an indoor environment, flooring materials can emit pollutants originating from the material itself (the so-called primary emission). Additionally, they can emit secondary pollutants: pollutants not originating from the material such as collected particles and chemical reactive products. And flooring materials can contribute with its surface and its emissions to "indoor chemistry", and therefore having an influence on indoor air quality (and thus exposure to different air pollutants) as well.

3.1. Primary emissions

Some flooring materials are well known for their chemical primary emissions. Polyvinyl chloride (PVC) flooring has shown to be a strong source for phthalates, which are a type of semi-volatile organic compound (SVOC) that are suspected to persist for a long-time indoors (Bornehag & Nanberg, 2010). Some studies indicate that SVOCs, but also some VOCs (volatile organic compounds), can be

Table 1. Potential contributions of flooring materials for each of the indoor environmental factors (and their aspects) to indoor environmental qualities

	Air quality	Thermal quality	Lighting quality	Acoustical quality
Air	Primary emission			
	Secondary emission			
	Indoor chemistry			
Thermal	VOC emission	Radiant heating		
Lighting		Absorption of sunlight	Glare; reflection	
			Illuminance differences	
			Colour impression	
Acoustical	Social behaviour			Acoustical performance

transported from air to the skin surface followed by transdermal permeation (Weschler, 2015). When compared with other flooring materials, exposure to PVC flooring material in early life was related to incidence of asthma during the following 10 years (Shu, Jönsson, Larsson, Nånberg, & Bornehag, 2014). Prevalence of asthma (one of the most chronic diseases among children) in most countries seems to be related not only to homes but also to indoor environments of schools (Eder, Ege, & von Mutius, 2006).

Another well-known primary emission is formaldehyde, of which the concentration has been related to asthma among children without history of atopy (Smedje & Nörback, 2001). Formaldehyde can be emitted by carpet backing and fabrics, but also by urea formaldehyde foam insulation, glues, fibreboard, pressed board, plywood and particleboard.

Recently, it was also pointed out that polychlorinated biphenyl (PCB)-containing sealants, paints and other building materials widely used in the 1950s to 1970s, might result today in numerous PCB-contaminated buildings (including schools) (Frederiksen, Andersen, & Gunnarsen, 2015). Whether existing flooring systems (incl. flooring materials) also contain PCB is important to investigate.

3.2. Secondary emissions

Flooring materials are potentially an important source of secondary pollutants. Collected/settled particles (dust) and chemical reactive products caused by cleaning and maintenance activities or lack of it, can also cause additional pollutants in a classroom, influencing the indoor chemistry.

For cleaning both the product that is used (e.g. mop use with bleach in a study by Csobod, Rudnai, & Vaskovi, 2010) and the effect cleaning can cause (e.g. removal of settled dust by vacuum cleaning in a study by Wålinder et al., 1999) have been found to correlate with health effects. School building condition (e.g. schools with run-down school facilities (Mendell et al., 2013) or moisture damaged schools (Haverinen-Shaughnessy, Borras et al., 2012; Meklin et al., 2005; Simons, Hwang, Fitzgerald, Kielb, & Lin, 2010; Takaoka, Suzuki, & Nörback, 2016) have shown to affect health, comfort and performance of children at schools. Cleaning frequency didn't show a clear relation with these occupant-related indicators (Van Dijken, Van Bronswijk, & Sundell, 2006).

The presence of carpets has shown to correlate with severity of certain health effects in some studies: with asthma in a study by Hansen, Bach, Kass Ibsen, and Osterballe (1987) and wheezing at night in a study by Csobod et al. (2010). It has been hypothesized that settled dust, including dust mites, allergens and other particles, is responsible for these relations. In a recent study, however, the amount of settled dust didn't correlate with health or performance of students (Haverinen-Shaughnessy, Shaughnessy, Cole, Toyinbo, & Moschandreas, 2015).

It should be noted that dust (particles) is a broad term used for particles in different shapes and sizes, from molecular dimensions to the sizes that can be seen with the eye (0.001 to ca. 100 μm). While particles smaller than 10 μm (PM_{10}) have been studied a lot (mostly outdoors), UFP (particles smaller than 100 nm) have hardly been studied in classrooms (Morawska et al., 2013), even though the hazardous nature of UFP is well-known.

To get rid of these secondary pollutants from flooring materials, several techniques have been developed: applying carpets to reduce dusts (Scheepers et al., 2015) and several (deep) cleaning processes (e.g. Black & McIntosch, 2012; Markowicz & Larsson, 2015). By-coming effects of these techniques as well as their performance under different circumstances are interesting topics for research.

3.3. Indoor chemistry

Reactions of compounds (originating from indoor and outdoor) present in the indoor air and on surfaces, even on people, also named indoor chemistry, can result into new products. For both indoor and outdoor chemistry, VOCs have been studied extensively. SVOCs, such as phthalates, however, have been understudied according to Nazaroff (2015).

4. Thermal quality

With an increase in temperature, the emissions of most VOCs increase as well. Therefore, thermal aspects of an indoor environment as well as of the flooring materials themselves can affect the indoor air quality.

4.1. VOC emission

In several studies was seen that increased classroom temperatures can have a negative effect on health and academic achievement (Haverinen-Shaughnessy & Shaughnessy, 2015; Haverinen-Shaughnessy, Turunen et al., 2012; Turunen, Toyinbo, Putus, & Nevalainen, 2014; Wargocki & Wyon, 2007). Whether this is related to an increase of emissions specifically by flooring materials, is not clear. But we do know that children are in general less sensitive to temperature changes, and have different metabolic rates for typical indoor activities (e.g. sitting–reading–listening–talking) than adults, which may explain the differences in thermal sensations when exposed to the same temperatures found by several researchers (e.g. de Dear, Kim, Candido, & Deuble, 2015; Havenith, 2007). We also know that children may be more susceptible than adults to effects of toxic exposure because they are in the process of maturation and have higher metabolic demands (Mendell & Heath, 2005).

4.2. Radiant heating

Flooring materials that can adsorb heat better than others will be more eager to contribute to overheating (through radiation), and thus are more vulnerable to an increase in VOC emissions. This radiant heat adsorption can be solar radiation, and is influenced by the colour of the material and the absorption capacity. Radiant floor heating is another way to increase the temperature of the flooring system and therefore might influence the emission rates.

To get rid of the "extra" emissions from the flooring systems, additional attention needs to be paid to the ventilation of the classroom. Most primary schools in the Netherlands have natural ventilation, operable windows, in combination with radiant heaters (radiators below the windows). Emissions caused by flooring materials as well as emissions caused by the children will not be removed efficiently. The question arises whether a full air-conditioning system, or even only a mechanical supply, is better for our children to be exposed to or not. Besides the energy issue, the thermal comfort aspects of such a system can be complex. Other combinations of heating and ventilating systems might be interesting to investigate. For example, displacement ventilation in combination with floor heating (instead of mixing ceiling ventilation) improved perceived indoor air quality and respiratory symptoms at a primary school (Norbäck, Wieslander, Zhang, & Zhao, 2011). But other combinations in relation to the role of the flooring material applied might be interesting to investigate as well.

5. Lighting quality

In theory, flooring materials can contribute to the lighting quality with their colour and surface characteristics in relation to the other surfaces, both in a positive and negative sense.

5.1. Glare/reflection

An environment with an appropriate lighting requires a certain brightness as well as even, glare-free lighting of a balanced spectrum. Smooth surfaces, in particular, might cause unwanted glare or reflection (of high luminance) when exposed to certain lighting conditions.

Several studies have shown that the quality of (day)lighting seems to have an effect on student learning (e.g. Heschong, 2002; Heschong Mahong Group, 1999), absenteeism (Hathaway, 1995) and on discomfort, such as glare and annoyance (Winterbottom & Wilkins, 2009). Additionally, daylighting (and patterns) vs. electrical lighting, window orientation and performance of school children have been studied (e.g. Küller & Lindsten, 1992; Tikkanen, 1979; Wu & Ng, 2003). In these studies, the role of the flooring material has not been addressed specifically.

5.2. Luminance differences or contrast
The difference between luminance of different surfaces is an important aspect of lighting quality as well. Too low luminance differences can result in a non-stimulating environment, while too high differences can cause tiredness because the eyes have to accommodate/adjust all the time. The luminance of a surface is determined by the reflectance and lighting level on the surface. The effect of luminance differences between a floor and other surfaces, on health, comfort and performance could therefore be an interesting topic of research as well.

5.3. Colour impression
Studies with adults have shown that different colours can directly affect an individual's impression of environmental parameters. A good example is the environmental parameter "Temperature": in general, light blue is experienced as cooler and red/orange as warmer. But also the psychological effects of light (e.g. colour and illuminance) can differ for different people. And younger children normally prefer bright colours and patterns, while adolescent prefer more subdued colours (Mahnke, 1996). In one study, it was shown that preferences for colour might even differ per child (Park, 2014). And different colour/light combinations of the indoor environmental surfaces seem to have an effect on perceptual performance of school children (e.g. colour of walls studied by Yildirim, Cagatay, & Ayalp, 2015) and also on their behaviour and mood (Wohlfart, 1986). Flooring materials have not been addressed in either of the studies.

6. Acoustical quality
Both external and internal noise can affect the health, comfort and performance of children. Young children seem far more susceptible to poor acoustic conditions than adults. Children with a hearing impairment (from a permanent hearing damage or a temporary condition such as a cold or ear infection) seem even more seriously affected by noise (Shield & Dockrell, 2003). But it also seems that bad room acoustic conditions can affect social behaviour of children. Because flooring materials can contribute to the acoustical performance of a room, sound-absorbing flooring materials have been applied to cope with this and other acoustical problems (Harris, 2015).

6.1. Acoustical performance
Inside a classroom, noise can be generated by teaching equipment (computers, projectors and so on), building services, and noise can be transmitted through the walls, floor and ceiling from other parts of the school. But the biggest source of noise is the pupils themselves. Studies have shown that noise adversely impacts the ability of teachers and children to communicate, as well as pupils' attention, memory, and thus motivation and academic achievement (Geller, Rubin, Nodvin, Teague, & Frumkin, 2007). But noise in a class room can also cause annoyance and stress responses (Lundquist, Holmberg, & Landstrom, 2000).

The annoyance experienced by noise has been studied less than the effects of noise on the performance of children. Dose-response relationships between noise and annoyance have been established for adults. Unfortunately, for children only few studies have been concerned with annoyance (Shield & Dockrell, 2003). However, associations between noise levels and performance or annoyance are not straightforward. Other parameters, for example speech intelligibility, reverberation time and signal to noise ratio, seem more promising indicators than noise level (Kjellberg, Ljung, & Hallman, 2008). How this relates to the performance of different flooring materials is a topic for research.

6.2. Social behaviour
That bad room acoustic conditions seem to affect social behaviour of children is an interesting recent finding. It is claimed that due to the background noise level, children make more noise and are more active. Mydlarz et al. (2013) compared environmental and acoustical factors in occupied school

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classrooms in recent built school buildings and found a correlation between noise levels and CO_2. Thus, a higher noise level may be associated with higher CO_2 level, insinuating a higher activity level.

7. Conclusions and directions for research

It is clear that indoor environmental conditions affect health, comfort and learning performance, but also that the behaviour and activities performed by the students influence the environmental conditions. Flooring materials can certainly influence indoor environmental conditions and indoor environmental conditions can influence the effect that flooring materials potentially have. The analysis above shows, however, that not many studies have considered flooring materials as a primary topic of research. Only some studies have addressed flooring materials, in particular from the air quality point of view.

In the frame of requirements in the European Construction Product Directive, primary emissions from construction products (which includes flooring materials) have been acknowledged as an important contributor to indoor air quality. As a consequence, next to the market available voluntary schemes with labels, a number of member states have introduced a national evaluation scheme for primary emissions of construction products (Bluyssen, 2015). In a number of those schemes, next to chemical testing (VOCs, particles, formaldehyde, etc.), odour testing is included. Whether they cover all potential contributors to indoor air pollution, is, however, not clear.

For a classroom, it is clear that we are dealing with children and teenagers, often in a setting with a high density, 25–30 students per classroom. The changing educational systems in many countries in the last decade, have resulted in more frequently working and learning independently by pupils. This not only leads to a greater individuality of what is learnt, but also leads to changes in interaction within the classroom (Oberdörster & Tiesler, 2008). Consequently, discussion groups, project groups and role-play seem to dominate the learning approach. This requires other seating, environmental needs and configurations. With these changes, the effect on room acoustics changes as well, and perhaps the role of the flooring material.

The interaction of a flooring material with its "changing" indoor environment is of particular interest for the thermal and lighting demands and loads. For example, the available dynamic daylighting vs. the demands of lighting patterns in a room to perform a certain task, or the differences in thermal requirements during the day vs. the limits of the available systems and controls. It is hypothesized that dynamic lighting, but perhaps also a dynamic thermal environment can have a positive influence on the well-being of a person. Nevertheless, our standards and guidelines claim otherwise.

Which brings us to the interaction of a flooring material with the other components (e.g. the lighting system, the ventilation system, the heating/cooling system and the educational system). At individual level, efforts are being made to provide local, individually controlled systems to provide comfortable microenvironments. How this affects the choice of a flooring material or even the role of the flooring material is an interesting topic to explore.

Current guidelines for healthy indoor environments within schools are in general using criteria that are originally set-up for adults, and focused on single factors and on stationary situations, which do not consider interactions between those factors, and certainly do not consider the flooring materials as a potential source or contributor (EU, 2014; RVO.nl, 2015).

In summary, to get more insight in the current and potential role of flooring materials on health, comfort and performance of children, there is a clear need for:

- A holistic analysis of classrooms and student performance, in real-life situations, in which flooring materials are considered as a potential contributor to IEQ, including classrooms with different space and systems configurations (e.g. heating, lighting, ventilation, educational setting and interior furnishings), environmental factors and other aspects (e.g. confounders).

- Experimental, quasi experimental studies, that would provide more insight in potential causal relationships at individual level, but also insight in the total picture and interrelationships between different space and systems configurations (e.g. heating, lighting, ventilation, educational setting and interior furnishings), environmental factors and other aspects (e.g. confounders).
- Besides questionnaires or performance tests, involve children in another way, for example through interactive techniques (e.g. using mock-ups, sketches and focus groups).

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Competing Interests
The authors declare no competing interest.

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