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Kindergartens and nurseries in central portugal. assessments of indoor environment quality

Pinto Manuel[1*], Lanzinha João[2], Viegas João[3], Infante Ana[4] and Freire Tiago[5]

[1]Professor, School of Technology & Management (ESTGV) - CONSTRUCT-LFC, Portugal

[2]Professor, LABSED - UBIMedical, C-made - Centre of Materials and Building Technologies, Faculty of Engineering University of Beira Interior (UBI), Portugal

[3]Principal investigator, National Laboratory for Civil Engineering (LNEC), Portugal

[4]Master engineer, School of Technology & Management (ESTGV), Portugal

[5]Master engineer, University of Beira Interior (UBI), Portugal

***Corresponding author:** mpinto@estgv.ipv.pt

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A B S T R A C T

The Indoor Environment Quality study takes on a very significant challenge when analyzed, mainly, in buildings that encompass a more sensitive and susceptible type of population, as is the case of children. To comply with a set of requirements, namely the concentration of pollutants and the conditions of hygrothermal comfort, is a necessary condition to keep an interior environment suitable for the permanence of the occupants. A research project, that studied Indoor Environment Quality in four buildings which hold nurseries and kindergartens, was carried out in two cities in central Portugal, Viseu and Covilhã. The following main conclusions may be drawn: most compartments are not comfortable in terms of ambient temperature, but the relative humidity has reasonable values. Air change rates generally have low values and the measured pollutants have worrying values. Based on the observed problems and reached conclusions, some recommendations are proposed.

Keywords: indoor environment quality (IEQ); indoor air quality (IAQ); nurseries, kindergartens (KGT); hygrothermal comfort; air change rates

Introduction

In developed countries, children spend most of their time at home or at school [1]. The health, well-being and general performance of the population are strongly related to the conditions of the interior environment [2]. There are currently a set of functional requirements that allow for increased occupant comfort due to the high permanence of the population inside the buildings. The quality of life of the occupants of buildings can affect their state of health and even the student's performance [3].

Indoor Environment Quality (IEQ) plays an important role in all permanently occupied buildings. However, in view of a particularly vulnerable population, special attention should be paid to child day care center (CDCC, is the school for children between 3 months and 3 years old; CDCC includes nursery, that is the compartment for babies over 3 months until the acquisition of walking) and kindergartens (KGT, that is the school for children between 3 and 6 years).

Studies in nurseries and KGT are rare, perhaps due to the difficulty in making observations in spaces where the introduction of equipment and people changes to children's habits. There are some studies at the international level, but in Portugal there are just few studies on this subject.

More research is needed to better describe the IAQ where the children are spending most of their time. Therefore, this research is intended to contribute to that effort by providing information on CDCC and KGT premises in Portugal. The relevance and novelty of this case study in Portugal is related to the character of the two towns involved, because both are located in the interior of central Portugal and present more stringent external environmental conditions (colder climate in winter), where people tend to reduce ventilation to keep the thermal comfort, which can cause poorer conditions for IEQ. It is also intended to analyses the influence of the discontinuous operation of the air conditioning in these spaces, a very common situation in Portugal.

The aim of this research is to assess the conditions of IEQ in living rooms of nurseries and KGT, namely by measuring the comfort conditions (ambient temperature end relative humidity), concentration of pollutants internally released (CO_2, TVOC and formaldehyde) as well as the respective ventilation rates (*ACH*), see Figure 1.

Figure 1. Location of Viseu and Covilhã towns - Portugal.

Literature review

Some studies show that young children are particularly susceptible to indoor air pollution because of their immature immune systems and smaller bodyweight [4].

There is evidence implicating air pollution in adverse effects on children's health. Effects of air pollution have mainly been investigated concerning lung development and function, respiratory diseases such as asthma, bronchitis, and cough, allergies, rates of infection in smaller children and deficits in neurobehavioral development. Concretely, the developing fetal lung, as well as the infant's lung, is more susceptible to injury by lung toxicants (including air pollutants) at doses below the no-effect level for adults [5].

Some risk factors identified in children included, namely, plastic materials, formaldehyde, children's activities and recent painting [6, 7]. In the same way, elevated risks were also reported, among others, for cleaning activities [6, 7].

Adequate ventilation significantly reduces indoor concentrations of pollutants. Low ventilation rates (below 0.5 h^{-1} air changes rate - *ACH*) are associated with increased absenteeism and respiratory symptoms in school and high allergic manifestations among children, namely, in a Nordic climate [8-10].

Children have different levels of thermal sensation, different metabolic rates, different clothing restrictions and different sensitivities to temperature changes. Levels of response between children also have a lot of variance and classroom activities are more diverse than adult activities over a typical day [11]. Children have a greater sensitivity to changes in their metabolism than adults and prefer lower temperatures than those predicted by the PMV model and the standard EN 15251 [12].

Despite the difficulties in doing studies in nurseries and KGT, some research has been done lately in buildings that house children. For example, St-Jean has shown that an area of 2.75m²/child helps to control body odors in play areas [13]. In the case of Portugal, the spaces and their minimum useful areas per room unit in CDCC, set for 8 children, must be at least 2 m²/child [14].

Ramalho concluded that carbon dioxide (CO_2) as a tracer of some pollution sources cannot be considered as a unique indoor air quality indicator. CO_2 is also often considered as a surrogate of the ventilation rate when the main pollution is caused by the human respiration. Hence, the study confirms that even with good ventilation conditions (i.e. low CO_2 level), the reduction of pollutant sources remains necessary to achieve a satisfactory IAQ [15].

Carreiro-Martins indicate an association between chemical and biologic contaminants at CDCC and wheezing in young children. Those exposures seem to be relevant for every wheezing child, independently of the asthma predisposition [16] and Kolarik suggests the importance of adequate ventilation in CDCC [17].

Depending on the research already carried out, it is necessary that adequate conditions of comfort are thought out from the design stage so that during the use phase they are easily achieved [18].

Ramalho [15] establishes the need for further research on the adverse effects intrinsic to CO_2 on human psychomotor performance (decision-making, problem-solving) and sensitive populations such as children. Ramalho [15] also recommends that the awareness of building owners, school directors, teachers and staff of kindergartens and schools, where higher CO_2 levels are observed compared to dwellings and offices, should be improved regarding, e.g. maintenance of ventilation system and ventilation through windows and doors opening to

Table 1. Reference concentrations of parameters measured

Parameters		Protection threshold in new buildings	Margin of Tolerance [a] (MT [b])	Protection threshold [a]
		[ppmv]	[%]	[ppmv]
Physicochemical pollutants [23]	TVOC - Total Volatile Organic Compounds	0.26 [c]	100	0.52 [c]
	CH_2O - Formaldehyde	0.08		
	CO_2	1250	30	1625
		Regulated / Recommended level		
Hygrothermal comfort	T [14, 24]	20 − 25°C		
	RH [14, 25]	30 − 70%		

Notes: (a) For existing buildings or new buildings without mechanical ventilation, for an average of 8 h, the Margin of Tolerance (MT) is defined to apply the protection threshold; (b) MT is the value added to "Protection threshold in new buildings" to get "Protection threshold in existing buildings and new buildings without mechanical ventilation", e.g. for TVOC: 0.6 mg/m³×100% = 1.2 mg/m³; (c) Value obtained for the molar mass of isobutylene. [26]

effectively reduce the impact of air stuffiness on health, performance and perceived comfort. The ventilation strategy must also take into account other risk factors such as noise, outdoor air pollution, thermal discomfort, etc., that could hinder an efficient ACH. Kolarik [17] found a significant inverse relationship between the number of sick days among nursery children and ACH.

Air quality and thermal comfort (T_{int} and RH) are important parameters for an indoor environment suitable for the occupants' permanence. It is also necessary to check the maximum concentrations of indoor air pollutants.

Table 1 shows the hygrothermal comfort conditions and the protection thresholds for physical-chemical pollutants.

It is also necessary to check the ventilation conditions. Adequate ventilation of the indoor air will restrict the degradation of the building elements, related to humidity, which will reduce the occupants' well-being. Ventilation must also be carefully designed so as not to cause thermal discomfort and excessive energy consumption are avoided.

The literature review show that the body of knowledge regarding the indoor air quality (IAQ) in CDCC and the impact of the ventilation in the improvement of IAQ is still small. Moreover, the research has been carried out mainly big towns. This research brings new information on the IAQ found in CDCC case studies in small Portuguese towns located at the countryside, where the range of external temperatures is wider and where the outdoor pollution is smaller. In this study the characteristics of the buildings are presented to highlight the impact of the construction characteristics in the IAQ.

Buildings and Compartments Studied - Physical Characterization

This article continues the research already carried out, resulting from two master degree dissertations [19, 20], so that complementary information (eg. used equipment and measurement methodology) can be found in an article recently published [21]. The measurement methods are described in the section 4.

City of Viseu

The city of Viseu is situated at an average altitude of 480 m and has approximately 1700 heating degree days (base 18°C) [22].

Two KGTs were analyzed: KGT 1 (children between 3 and 5 years old): 5 living rooms and 1 dining hall; KGT 2 (children between 1 and 5 years old): 8 living rooms, see Table 2.

Table 3 describes the compartments studied, namely, indoor and outdoor solar protection and the material and system for opening the windows.

Table 2. Characterization of the buildings and compartments studied - Viseu

	Buildings			Compartments			
	Year of construction	Climate control/ heating system	Ventilation system	Designation	Predominant orientation	Area [m²]	Usual maximum occupancy
KGT 1 [a]	18th century and rehabilitation in 1989	Intermittent heating with electric radiators	NV [c]	Living room 1	NW	53.83	2 educators and 19 children
				Living room 2	SW	30.16	2 educators and 20 children
				Living room 3	NW and SW	38.66	2 educators and 19 children
				Living room 4	NW and SW	34.55	2 educators and 20 children
KGT 2 [a]	1933 and rehabilitation in 1983	Intermittent heating with electric radiators	NV [c]	Living room 1	E	43.25	2 educators and 19 children
				Living room 2 [b]	S	61.46	4 educators and 28 children
				Living room 3	S	46.67	2 educators and 23 children
				Living room 4	S	53.99	2 educators and 16 children

Notes: (a) Non-systematic opening of windows when cleaning; daily cleaning with aqueous solution; (b) It also serves as a cafeteria; (c) The building does not have a ventilation system specifically designed and constructed. Ventilation is achieved by the permeability of the envelope - Natural Ventilation

Table 3. Description of the compartments studied - Viseu

Edifice	Rooms	Ceiling	Walls	Flooring	Windows	Solar Protection	
						Interior	Exterior
KGT 1	Living room 1	Cork	Plastered	Linoleum	Wood; single glazing	Blackout curtains	-
	Living room 2						
	Living room 3	Plastered		Ceramic mosaic	Single glazing; aluminum		
	Living room 4						
KGT 2	Living room 1	Cork	Plastered	Linoleum	Single glazing; aluminum	Semi-opaque curtains	-
	Living room 2	Plasterboard			Wood; single glazing	Wooden shutters	
	Living room 3	Cork			Double glazing; aluminum	-	PVC blinds
	Living room 4						

City of Covilhã

The city of Covilhã has an average altitude of 750 m and 2000 heating degree days (base 18°C) [22].

Two KGT were analyzed: (1) KGT 3 (children between 3 and 6 years old); (2) KGT 4 (children between 3 and 6 years old; babies between 4 and 12 months old), see Table 4.

Table 5 describes the compartments studied, namely, indoor and outdoor solar protection and the material and system for opening the windows.

Table 4. Characterization of the buildings and compartments studied - Covilhã

	Buildings			Compartments			
	Year of construction	Climate control / heating system	Ventilation system	Designation	Predominant orientation	Area [m²]	Usual maximum occupancy
KGT 3 [a,b]	1947	Intermittent heating with water radiators	RR: MV [d] – intermittent extraction (works only when using the RR)	Living room	W	35.37	2 educators and 8 children
				Dining hall	E	50.74	2 educators and 20 children
				Dormitory	E	51.86	2 educators and 30 children
KGT 4 [a]	1988	Intermittent heating with water radiators; HVAC [c] in the dining hall	RR [e]: NV or MV-intermittent extraction	Living room [c]	W	64.40	2 educators and 25 children
				Dining hall	S	193.60	13 educators and 70 children
				Nursery	N	46.75	3 educators and 10 babies

Notes: (a) Opening of windows when cleaning; daily cleaning with water; (b) Exterior walls without thermal insulation; (c) Can also be used as a dormitory; (c) HVAC: Heating, Ventilation, and Air Conditioning; (d) Mechanical Ventilation; (e) Restroom

Table 5. Description of the compartments studied - Covilhã

Edifice	Rooms	Ceiling	Walls	Flooring	Windows	Solar Protection	
						Interior	Exterior
KGT 3	Living room	Plastered	Plastered	Wooden parquet	Single glazing; aluminum	Opaque fabric shutter blinds	-
	Dining hall			Ceramic mosaic			
	Dormitory						
KGT 4	Living room	Plastered	Plastered	Wooden parquet	Single glazing; aluminum	Opaque fabric shutter blinds + opaque curtains	-
	Dining hall	Metallic suspended ceiling	Plastered+ Wood paneling	Linoleum		Opaque fabric shutter blinds	
	Nursery	Plastered	Plastered + Wood paneling	Cork tile		Horizontal blinds + opaque curtains	

Experimental Campaign Presentation and Analysis of Results

Viseu - Experimental Conditions

Measurements of exterior temperature were obtained from the site Wunderground [27]. Whenever possible, it was avoided to place the equipment close to places, namely windows and air conditioning equipment, which could influence the measurements of the interior environmental parameters. Metabolic CO_2 was used, as described in the standards ASTM E741 [28] and ASTM D6245 [29], to determine *ACH*, using the decay technique, in the post-occupation periods. The Portuguese Technical Note TN-SCE-02, 2009 (This document supports the application of Portuguese regulations in the area of IAQ) [26], allows, for measuring TVOC and formaldehyde, the use of "Photoionization Detectors" (PID). In both cities, equipment was used with the same measuring principle.

Pollutants in the compartments were continuously measured. Measurements were taken during periods of occupation [7:30 a.m. to 7:30 p.m.]. Only one point of analysis of the various parameters was carried out in each compartment, in view of the available equipment [26].

The experimental campaigns took place in January 2016, the first, and between April and May 2016, the second.

The main measurement conditions, parameters and measurement equipment can be consulted in [21]. The accuracy of measurements is ±0.50 ºC for temperature, ±2,5% for relative humidity, ±50 ppm (Telaire 7001) or 2.75% + 75 ppm (Fluke 975 AirMeter) for CO_2 concentration measurement and ±5% of the display reading ± one digit for TVOC.

Covilhã - Experimental Conditions

To assess the *ACH*, the criteria already presented for the location of the equipment inside the compartments were followed. The weather station at the University of Beira Interior (UBI), located at approximately 680 m altitude, was used to measure the relative humidity and outside temperature. Each reading record was performed continuously for a minimum period of 5 minutes [26]. The measurements of formaldehyde were punctual, in view of the limitations of the device, having recorded, measurements every 5 minutes, the maximum value of 3 measurements. The experimental campaigns took place between February and June 2014, the first, and between April and May 2015, the second. In the 2nd experimental campaign, measurements were only taken at KGT 4. The measurements refer to the usual period of occupancy: 7.00 a.m. to 7.00 p.m.

The main measurement conditions, parameters and measurement equipment can be consulted in [21] and their accuracy was referred to in the section before.

Analysis criteria

According to Table 1, the following situations were considered excessive and inadequate:

- for an average of 8h, CO_2 concentration greater than 1625 ppm;
- for an average of 8h, TVOC concentration greater than 0.52 ppm;
- for an average of 8h, CH_2O concentration greater than 0.08 ppm;

- indoor temperatures outside the acceptable range [20ºC; 25ºC] for more than 20% of the time;
- RH_{int} outside the range [30%; 70%].

City of Viseu

KGT 1 - 1st experimental campaign

In the living rooms of KGT 1, the average indoor temperatures were below those considered reasonable for the existence of thermal comfort in the studied compartments (values not shown). There is a cyclic variation of the interior temperature in all the compartments analyzed. This variation is due to the occupation of the compartments and the fact that the heating with electric radiators is intermittent (the level of individual intensity of heat release from the radiators is regulated by the users' thermal perceptions). The analyzed compartments do not present worrying values of average *RH*, except for living room 4, which presents an average value higher than the recommended maximum limit (values not shown).

The CO_2 and TVOC pollutants measured in KGT 1 are analyzed statistically in Table 6. We can conclude, based on Table 6, that: (1) During the period of habitual occupation, living rooms have a high average of CO_2 values; (2) The values of the standard deviation of the TVOC are high, and it can be concluded that the parameters with more influence (type of activities and ventilation rate) are quite variable during the occupation period; (3) The maximum CO_2 value, obtained in an average of 8 hours, was always higher, in all rooms, than the protection threshold (see Table 1); (4) Living room 4 has a maximum value for the average of TVOC above the protection threshold (see Table 1).

Figure 2 shows, for living rooms 1 and 2 of KGT 2, thermal comfort using the adaptive model proposed by LNEC [30]. In the LNEC model, considering the arithmetic average between T_{int} (indoor temperature) and T_{mp} (running mean outdoor temperature; ASHRAE 55, 2020 [31]; EN ISO 7730, 2005 [32]), one can calculate the "Operative temperature" with good approximation.

The results in the living room 1 and 2, considering the use of central heating with electric radiators (active air conditioning), revealed the existence of a thermally comfortable environment, with the temperature data, most of the time, within the established "comfortable" guideline values.

Table 6. KGT 1 compartments and pollutants, statistical analysis: 1st experimental campaign (11 to 15 January)

	CO_2 [ppm]			TVOC [ppm]		
Compartment	Max	$\mu \pm \sigma$	Maximum of 8 h average (n = 180)	Max	$\mu \pm \sigma$	Maximum of 8 h average (n = 50)
Living room 1	3194	1582 ± 611	1994	1.00	0.26 ± 0,24	0.27
Living room 2	3050	1732 ± 592	2110	0.58	0.17 ± 0,17	0.18
Living room 3	4130	2236 ± 760	2599	0.31	0.13 ± 0,12	0.13
Living room 4	3984	2308 ± 814	2745	1.73	0.60 ± 0,54	0.62

Note: The maximum value that occurs in sequentially-calculated 8 h average (n for each living room) is called "Maximum of 8 h average"; μ is the mean (arithmetic mean); σ is the standard deviation

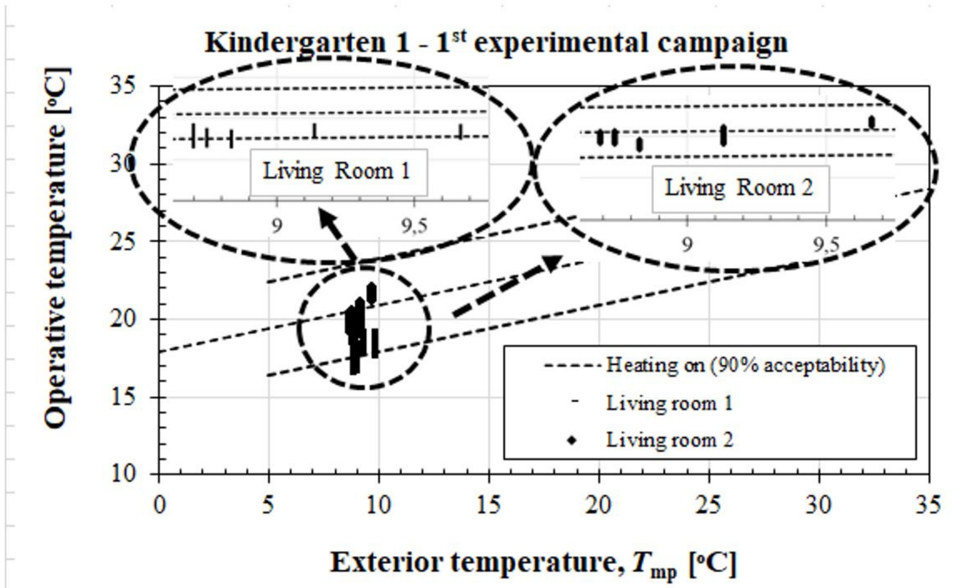

Figure 2. Adaptive method of the LNEC - assessment of thermal comfort in KGT 1: 1st experimental campaign.

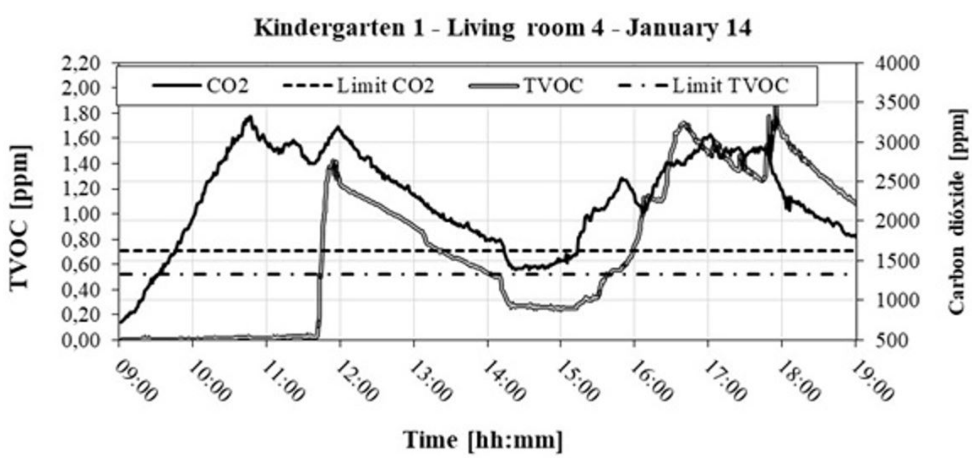

Figure 3. CO_2 and TVOC in living room 4 of KGT 1: 1st experimental campaign (14 January).

According to Figure 3, it is possible to observe that for living room 4 the maximum limit of TVOC is exceeded during a long period analyzed. The high concentrations of TVOC may reflect the use of teaching materials, such as the use of paints and glues (materials often used in handicrafts), the exposure of works in the living room and the existence of poor ventilation conditions. The third maximum peak of TVOC occurs around 6 pm, the time that corresponds to the usual cleaning period. Regarding CO_2, its concentration must be associated with human breathing (in the absence of sources with combustion) and also due to the existence of poor ventilation conditions.

From the results presented in Table 7, *ACH* of living rooms 3 and 4 in KGT 1, we may conclude that the *ACH* are well below the regulatory value in both living rooms analyzed. The minimum values for fresh air flows (ACH_{RECS}) were calculated solely according to the occupation (point 2.2.1 of Ordinance 353-A / 2013 [23]), no account was taken of the polluting load due to the materials of the building and use.

Table 7. KGT 1 living rooms 3 and 4 - *ACH*. 1st experimental campaign

Compartment	ACH_{av} [h^{-1}] [a]	q_{RECS} [$m^3/(h \times person)$] [b]	Volume [m^3]	Maximum usual occupancy-number of residents	ACH_{RECS} [h^{-1}] [c]
Living room 3	0.30	28	104.38	21	5.63
Living room 4	0.31	28	93.29	22	6.60

Notes: (a) A total of 5 trials were used to determine average *ACH* for living room 3 and 8 for living room 4 (the tests were carried out in the post occupation periods); (b) q_{RECS} means "Air flow rate", obtained following;[23] (c) ACH_{RECS} means "Air change rate", obtained following.[23]

For the city of Viseu and in the 1st experimental campaign, only the results of KGT 1 are presented because KGT 2 does not present such problematic results with regard to comfort conditions or IAQ.

City of Covilhã

1st experimental campaign

Table 8 shows the results of the pollutant measurements.

Regarding the values presented and taking into account the measurement period (≈ 5 min), we may conclude that: (1) KGT 3 has high concentrations of TVOC in the living room, which may reflect, in particular, poor ventilation and maintenance conditions (e.g., inadequate cleaning products) and the use of teaching materials (e.g. paintings and glues); (2) Two compartments (KGT 3: living room; KGT 4: nursery) have high CO_2 values, which may reflect, in particular, poor *ACH* or over-occupation for existing ventilation conditions; (3) The nursery of KGT 4 have high levels of formaldehyde. No potential source has been identified, which may be justified by coatings or materials used occasionally.

Table 8. Pollutant concentration measured in the 1st experimental campaign.

	Compartment	TVOC [ppm] $_{Max}$ [b]	CO_2 [ppm] $_{Max}$ [b]	CH_2O [ppm] $_{Max}$ [b]
KGT 3 (April)	Living room	0.62	1645	0.05
	Dining hall	0.37	842 [a]	0.03
	Dormitory	0.34	886 [a]	0.02
KGT 4 (June)	Living room	0.46	924	0.04
	Dining hall	0.19	841 [a]	0.04
	Nursery	0.25	2518	0.08

Notes: (a) measurement obtained outside hours of use; (b) maximum value of 3 means of 5 minutes each.

Figure 4 and Table 9 show the hygrothermal comfort conditions.

We can conclude, based on Figure 4 and Table 9, that: (1) The indoor temperature has a cyclical variation; (2) KGT behave differently: KGT 4 does not have pre-emptive values in terms of average temperature or relative humidity; KGT 3 has values well below those reasonable for temperature in the heating season. These temperatures can be explained by the different conditions of thermal insulation of the envelope of the studied buildings; (3) The temperatures are below the regulatory ones in the different compartments analyzed; (4) Two compartments of KGT 4 present relative humidity values that stay above the upper limit a considerable time period (Living room and Nursery).

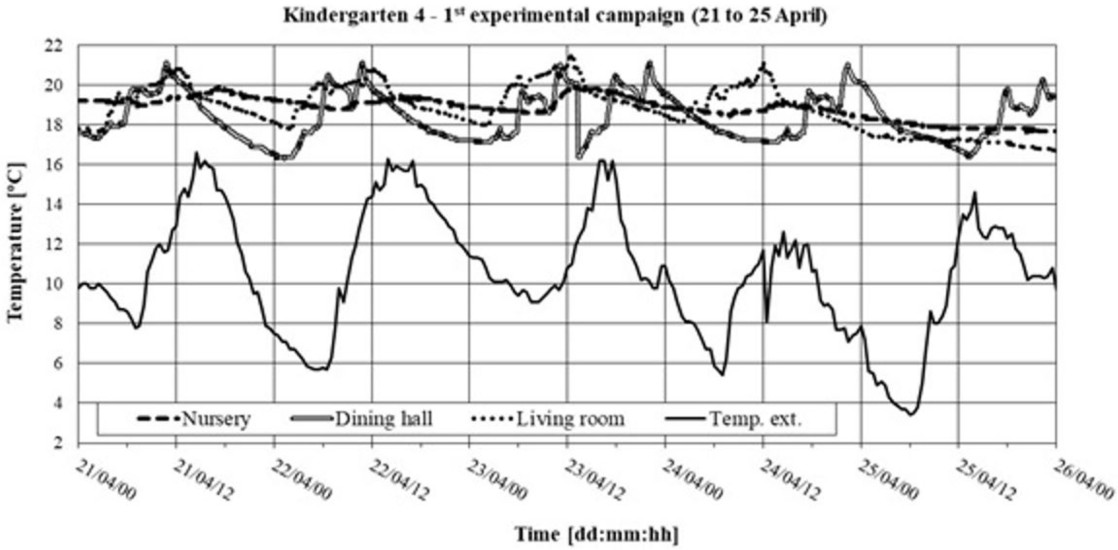

Figure 4. Temperatures at KGT 4: 1st experimental campaign (21 to 25 April, Monday to Friday).

Table 9. Statistical analysis of hygrothermal parameters recorded in the two KGT: 1st experimental campaign (March-May).

		T_{int} [°C]			RH_{int} [%]			T_{ext} [°C]	ΔT[a] [°C]
	Compartment	$\mu \pm \sigma$	*Perc*[b] ≤ 20°C	*Perc* ≥ 25°C	$\mu \pm \sigma$	*Perc* ≤ 30%	*Perc* ≥ 70%	$\mu \pm \sigma$	
KGT 3 (March-April)	Living room	17.1 ± 1.7	94	0	57 ± 7	0	2	10.7 ± 4.7	6.4
	Dining hall	19.7 ± 1.9	61	0	46 ± 6	0	0	11.5 ± 4.5	8.2
	Dormitory	18.5 ± 1.8	78	0	53 ± 9	0	1	10.7 ± 4.7	7.8
KGT 4 (April-May)	Living room	20.6 ± 1.8	31	1	65 ± 5	0	11	15.7 ± 5.3	4.9
	Dining hall	19.9 ± 2.3	48	0	56 ± 6	0	2	"	4.2
	Nursery	19.7 ± 1.3	54	0	65 ± 5	0	18	"	4.0

Notes: (a) ΔT is the difference between the means of T_{int} and T_{ext}; (b) *Perc* is the percentage of time that exceeds a certain value

2nd experimental campaign

The 2nd experimental campaign took place in May 2015. The concentration of pollutants and *ACH* are shown in Table 10.

Figure 5, dining hall, shows the concentrations of TVOC and CO_2. The points with maximum levels of TVOC are identified. The starting points of the decay technique, which served to determine the *ACH*, are also identified.

We may conclude, from Table 10 and Figure 5, that: (1) CO_2 level is too high a significant period of time in the nursery; (2) The nursery presents very low values for *ACH*. Compared to regulatory values, the dining hall also presents low values; (3) In the dining hall, the peak of TVOC occurs at 10 am on Friday, followed by a decay. The weekend cleaning action followed by a window opening can produce this peak.

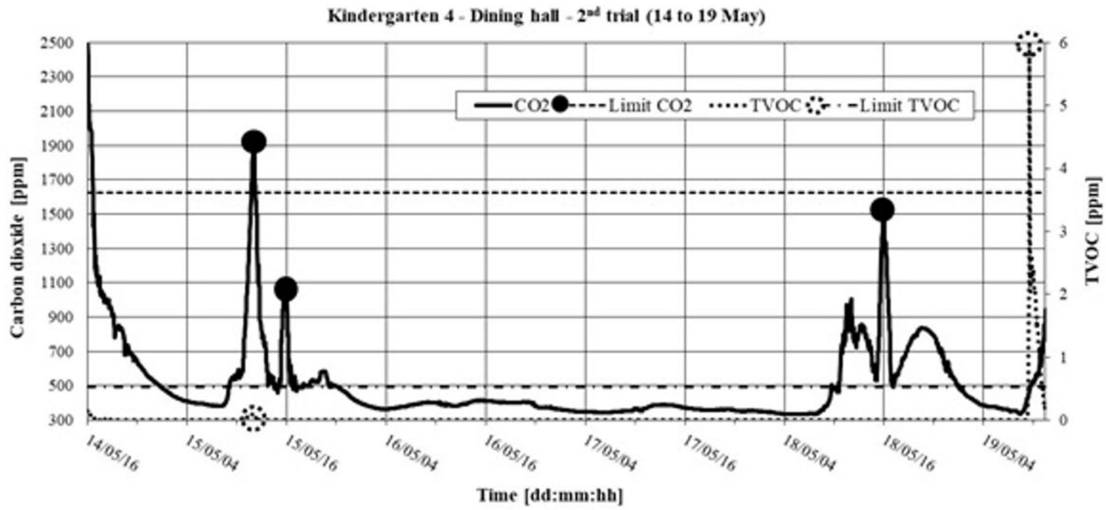

Figure 5. Dining hall - TVOC and CO_2 - in the KGT 4: 2nd experimental campaign (14 to 19 May).

Table 10. Pollutant concentration measured in the 2nd experimental campaign (May) at KGT 4 and calculation of *ACH*.

		CO_2 [ppm]		ACH_{av} [h^{-1}]	ACH_{RECS} [h^{-1}]	TVOC [ppm]		CH_2O [ppm]$_{Max}$
	Compartment	$\mu \pm \sigma$	*Perc* ≥ 1625			$\mu \pm \sigma$	*Perc* ≥ 0.52	μ
KGT 4 (May)	Dining hall	700 ± 377	3.9	0.89	2.9	0.11 ± 0.48	5.3	6.03
	Nursery	1222 ± 314	15.9	0.09	1.3	0.03 ± 0.04	0.0	0.26

Notes: (1) To determine the average *ACH*, a total of 4 trials were conducted in the dining hall and 1 in the nursery; (2) The minimum values for fresh air flows (ACH_{RECS}) took into account the occupation and the polluting load due to the materials of the building and use; (3) av is the average (arithmetic mean)

Discution

The following main results may be drawn from KGT in Viseu:

- the KGT 1 compartments showed poor air conditioning conditions in the heating season, presenting in most cases excessive percentages of time (≥ 20%) with temperature values below the regulation (20ºC);
- most KGT 1 compartments do not have worrying values of average *RH*;
- the KGT 1 compartments have a maximum of CO_2 averages (8 hours) above the protection threshold;
- living room 4 of KGT 1 has a maximum value, above the protection threshold, for the average of TVOC (8 hours);
- the existence of a thermally comfortable environment in the living room 1 and 2 (KGT 1) is observed, by applying the adaptive comfort model proposed by LNEC;
- for living room 3 and 4, *ACH* have values generally well below the regulations.

The following main results may be drawn from KGT in Covilhã:

- the KGT 4 nursery has high values of the measured pollutants;
- the compartments present excessive percentages of time with temperatures below the regulations;

· large part of the compartments, except for two, do not present worrying relative humidity values;

· the KGT 4 nursery has very low values for *ACH*.

In general, the results show indoor temperature that is low (see figure 2) and, sometimes, below the comfort condition (see Table 9 and Figure 4). In the interaction with the building, the users tend to keep the windows closed, when trying to reach the thermal comfort. As the ventilation is made just using the natural permeability of the buildings and depending on the natural actions (wind and indoor-outdoor temperature difference), the resulting ventilation rate is too low, when considering the needs of every room due to the human occupation (see Table 7 and Table 10, where the values of ACH_{RECS}, corresponding to the regulatory ventilation rate that is required according to the human occupation, shall be compared with the measured ventilation rate ACH_{av}). The study reveals that the indoor pollutants concentration is too high (see Table 6, KGT 3 living room and KGT 4 nursery at Table 8 and Figure 3) and that sometimes the concentration stays significant time periods above the protection threshold, that allows to consider that in such cases the health can be affected.

Recommendations and Conclusions

This study was carried out to assess the IEQ in living rooms of nurseries and KGT in towns in the countryside of Portugal, where is likely to expect lower IEQ due to the more adverse climate.

From the analysis of the results of the two cities and for the heating season the most relevant conclusions are:

· the compartments are generally insufficiently heated;

· the pollutants measured are above the protection threshold:

· ventilation rates (*ACH*) are reduced.

The previous results imply the need for action concerning heating, maintenance, and ventilation conditions so that the spaces operate within the appropriate conditions of comfort and air quality.

The organizational recommendations are as follows:

· air conditioning conditions can be improved by raising the awareness of management/directors, educators and assistants to the importance of turning the heating on continuously throughout the entire period of operation of the interior spaces, as well as to the importance of regulation of radiators to appropriate intensity levels;

· when using teaching materials, namely glues and paints, ventilation must be intensified by opening windows. After carrying out manual work with these materials, they must also be exhibited in more ventilated places. Alternatively, less polluting materials may be used;

· the number of residents in the living rooms should be limited/controlled to respect a minimum ratio of 2 m^2/child in CDCC;

· ventilation conditions can be improved by intensifying the practice of natural ventilation. Windows and doors should be opened after the cleaning period and even when the rooms are empty (at least 1 hour per day and never less than 15 minutes);

· for interior maintenance, ammonia cleaners, organic solvents and other chemicals which significantly affect the

IEQ should not be used.

The conditions of ventilation and hygrometry can be improved by implementing the following (in order of effectiveness):

· mechanical systems, including air intake devices in windows;
· exhaust fans with a suitable flow rate for each compartment in the exterior wall;
· dehumidifiers where high moisture contents have been recorded.

Despite the valid conclusions, this study has some limitations, such as: being limited to the study of buildings in two towns and only three pollutants. Thus, this study should extend to other locations in the countryside of Portugal and cover other pollutants (eg. $PM_{2.5}$).

In Portugal nurseries and KGT in some cases may have poor Indoor Environment Quality (IEQ). The highlights of this research are:

· discontinuous heating of spaces (widely used in Portugal) can lead to discomfort, even taking into account the low value of the assumed comfort temperature (20ºC);
· when using teaching materials, namely glues and paints, ventilation must be intensified by opening windows;
· ventilation conditions must be improved, namely by intensifying the practice of natural ventilation.

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Nomenclature

ACH	Air change rate, [h^{-1}]
CH_2O	Formaldehyde
CDCC	Day Care Center
CO_2	Carbon dioxide
E, N, NW, S, SE, SW, W	Cardinal points: E - East; N - North; NW - Northwest; S - South; SE - Southeast; SW - South-west; W - West
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
KGT	Kindergartens
LNEC	National Laboratory for Civil Engineering
Max	Maximum

MT	Margin of Tolerance
MV	Mechanical Ventilation
n	Number of 8h averages of measurements
NV	Natural Ventilation
Perc	Percentage of time that exceeds a certain value
PMV	Thermal comfort model adopted in the standard ISO 7730:2005
q	Air flow rate, [m^3/h]
RH	Relative Humidity, [−]
RR	Restroom
T	Temperature, [°C]
T_{mp}	Running mean outdoor temperature, [°C]
TVOC	Total Volatile Organic Compounds
Greek symbols	
D	Difference
m	Mean (arithmetic mean)
σ	Standard deviation
Subscripts	
av	Average (arithmetic mean)
ext	Referring to the exterior
int	Referring to the interior
Max	Maximum
RECS	Referring to Ordinance 353-A/2013

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