Applicability and sensitivity of the TAIL rating scheme using data from the French national school survey

Minh Tien Tran[1, 2, *], Wenjuan Wei[1], Claire Dassonville[1], Corinne Mandin[1], Mickael Derbez[1], Christophe Martinsons[1], Pascal Ducruet[1], Valérie Héquet[2] and Pawel Wargocki[3]

1 Scientific and Technical Center for Building (CSTB), Health and Comfort Department, French Indoor Air Quality Observatory (OQAI) 77420 Champs-sur-Marne, France
Presenting author: Minh Tien Tran

2 IMT Atlantique, CNRS, GEPEA, UMR 6144 CEDEX 3, 44307 Nantes, France

3 International Centre for Indoor Environment and Energy, Department of Environmental and Resource Engineering (DTU SUSTAIN), Technical University of Denmark (DTU) 2800 Lyngby, Denmark

ABSTRACT

The TAIL rating scheme for assessing the quality of Thermal, Acoustic, Indoor air, Luminous, and the overall environment was initially developed to assess indoor environmental quality (IEQ) in hotels and offices. To broaden the use of the TAIL rating scheme to other buildings, its applicability for schools was studied. Two additional parameters, i.e., reverberation time and nitrogen dioxide concentration, were included to account for the specificities of the building use and population. The TAIL rating scheme for schools was applied to the data collected through a national survey performed in France in 602 classrooms between 2013 and 2017 to examine the scheme's feasibility and sensitivity. The results show that using the scheme makes it possible to discriminate IEQ conditions in schools and helps identify problems that may lead to health risks or discomfort, such as insufficient ventilation or overheating during winter. It is concluded that the TAIL rating scheme adapted to schools allows tangible assessment of classroom IEQ and identification of problems requiring improvement, thus promoting a better school environment that eventually will support the proper development of children.

KEYWORDS

Thermal, ventilation, acoustic, lighting, perception

1 INTRODUCTION

Nowadays, humans stay indoors more and more. Extreme climate change can further intensify this trend. Indoor environmental quality (IEQ) is thus an important parameter. IEQ comprises the thermal environment, the acoustic environment, the indoor air quality (IAQ), and the lighting environment. A substantial number of studies have demonstrated the influence of IEQ on occupants' health, comfort, and well-being. These effects are not only limited to adults but also to children in schools. Children are more susceptible to inadequate IEQ as their bodies are still under-development. It is, therefore, essential to create a rating scheme for assessing the quality of the school environment. With this vision in mind, the TAIL-rating scheme for schools was developed. Initially, the TAIL rating scheme was developed for hotels and offices as a part

of the European ALDREN project, promoting the in-depth energy renovation of buildings [1]; the TAIL rating for schools is an adaptation of the original TAIL rating scheme with additional parameters relevant to these environments. Reverberation time for the acoustic environment and nitrogen dioxide (NO_2) concentration for indoor air quality were added; updates were made to match the new World Health Organization (WHO) air quality guidelines. A feasibility and sensitivity analysis was performed using measurement data from the French National Schools' survey (2013-2017), coordinated by the Scientific and Technical Centre for Building (CSTB).

2 RESULTS AND DISCUSSION

Table 1 presents all parameters in the TAIL rating scheme for schools, with all threshold values for each quality category. The following section presents the results of the TAIL-rating scheme, with Table 2 presenting details of the TAIL classification for each component, and parameter individually.

2.1 Thermal environment

Of the 305 schools where the thermal environment was assessed, the measurements in 237 schools were made in the heating season and 68 schools in the non-heating season. Figure 1 shows the distribution of all measurement instances for heating and non-heating seasons. While generally measured air temperatures in the non-heating season are higher than in the heating season, there were still occurrences in which recorded air temperatures from the heating season were as high as in the non-heating season. This suggests overheating in classrooms measured during the heating season. Closely examining the schools measured during the heating season, Figure 2 regroups and displays all measurement instances in the 237 schools during the heating season with colored horizontal lines corresponding to the quality level. The figure shows that a more significant variation was observed in schools having low quality according to the TAIL rating scheme. This could be due to low air temperature in the early morning and/or improper use of the heaters leading to high air temperature.

2.2 Acoustic environment

The acoustic environment was assessed using only the background noise level recorded during the school´s standard period of occupation (09h00 to 17h00) but made on the weekend with no occupants. This choice is guided by the fact that the sound of the particle measurement device cannot be dissociated from the background noise level during measurements on weekdays. The results obtained show different quality levels. A Wilcoxon non-parametric test showed that compared to a school located close to medium to low traffic, schools located in high-traffic zones had a higher background noise level both on Saturdays (p-value = $7.6.10^{-4}$) and Sundays (p-value = $1.27.10^{-2}$).

2.3 Indoor air quality (IAQ)

IAQ was assessed using seven parameters: benzene, formaldehyde, visible mold RH, CO_2, NO_2, and $PM_{2.5}$. Figure 3 presents all CO_2 concentration measurements separated by measured season. Schools where measurements were made during the heating season, had higher CO_2 concentrations than schools measured during the non-heating season, as windows were probably less open. Figures 4 and 5 present two opposite trends in relative humidity measured during the heating and the non-heating season. From the quality category I (high) to IV (low), the measured relative humidity tended to decrease during the heating season and increase during the non-heating season. Figure 6 shows a map of all 307 schools where NO_2 concentration was

color-coded by their corresponding quality category. While most schools achieved the green-high (category I) quality level, schools located in highly populated areas achieved a lower quality level. Following the same principle, Figure 7 shows the map of the quality level of measured $PM_{2.5}$. Compared to the NO_2 concentration, measured $PM_{2.5}$ quality were low but with no observed difference between urban and rural area. This resonated with previous findings, as $PM_{2.5}$ sources are a mix of both indoor and outdoor and from its ubiquitous nature [2].

2.4 Visual environment

The visual environment assessments focused solely on measuring artificial lighting levels at students' desks and on the writing boards. The overall results for each classroom were determined on the basis of the lowest recorded measurements.

2.5 Overall IEQ

303 out of 308 schools had the lowest (category IV) red quality category, and five schools had the next to the lowest orange quality category (category III). This result will urge schools to adopt a holistic approach to assessing the current state of IEQ. They also show the advantage of considering all four components simultaneously when making decisions for IEQ improvement, which is a fundamental principle of the TAIL rating scheme, with no compromise regarding ensuring optimal IEQ in educational institutions.

Table 1: IEQ parameters included in the TAIL rating scheme for schools

Parameter	Category I	Category II	Category III	Category IV
	Quality of the thermal environment (T)			
Air temperature	Building with mechanical cooling			
	Heating season: 22 ± 1 °C Non- heating season: 24.5 ± 1 °C	Heating season: 22 ± 2 °C Non- heating season: 24.5 ± 1.5 °C	Heating season: 22 ± 3 °C Non- heating season: 24.5 ± 2.5 °C	If other quality levels cannot be achieved
	Building without mechanical cooling			
	Heating season: 22 ± 1 °C Non- heating season: Upper limit: 0.33 θ_{rm} + 18.8 + 2°C Lower limit: 0.33 θ_{rm} + 18.8 - 3°C θ_{rm}: outdoor running mean temperature	Heating season: 22 ± 2 °C Non- heating season: Upper limit: 0.33 θ_{rm} + 18.8 + 3°C Lower limit: 0.33 θ_{rm} + 18.8 - 4°C	Heating season: 22 ± 3 °C Non- heating season: Upper limit: 0.33 θ_{rm} + 18.8 + 4°C Lower limit: 0.33 θ_{rm} + 18.8 - 5°C	If other quality levels cannot be achieved
	Quality of the acoustic environment (A)			
Background noise level	≤ 30 dB(A)	≤ 34 dB(A)	≤ 38 dB(A)	If other quality levels cannot be achieved
Reverberation time	Classroom with volume < 250 m^3: 0.4 - 0.6 s Classroom with volume ≥ 250 m^3: 0.6 – 0.8 s	Classroom with volume < 250 m^3: 0.6 - 0.8 s Classroom with volume ≥ 250 m^3: 0.8 – 1.2 s	No criteria	If other quality levels cannot be achieved

	Quality of the indoor air quality (I)			
Benzene concentration	< 2 µg/m^3	≥ 2 µg/m^3	No criteria	≥ 5 µg/m^3
CO_2 concentration	550 ppm above outdoor concentration	800 ppm above outdoor concentration	1350 ppm above outdoor concentration	If other quality levels cannot be achieved
Formaldehyde concentration	< 30 µg/m^3	≥ 30 µg/m^3	No criteria	≥ 100 µg/m^3
NO_2 concentration	< 10 µg/m^3	< 20 µg/m^3	No criteria	≥ 20 µg/m^3
$PM_{2.5}$ concentration	< 5 µg/m^3	≥ 5 µg/m^3	No criteria	≥ 15 µg/m^3
Radon concentration	< 100 Bq/m^3	≥ 100 Bq/m^3	No criteria	≥ 300 Bq/m^3
Relative humidity	30 – 50%	25 – 60%	20 – 70%	If other quality levels cannot be achieved
Ventilation rate	≥ (10 L/s/p + 2.0 L/s/m^2 floor)	≥ 7 L/s/p + 1.4 L/s/m^2 floor and < 10 L/s/p+ 2.0 L/s/m^2 floor	≥ 4 L/s/p + 0.8 L/s/m^2 floor and < 7 L/s/p + 1.4 L/s/m^2 floor	If other quality levels cannot be achieved
Visible mold inspection	No visible sign	< 400 cm^2	< 2500 cm^2	≥ 2500 cm^2
	Quality of the lighting environment (L)			
Daylight factor	≥ 5.0%	≥ 3.3%	≥ 2.0%	If other quality levels cannot be achieved
Artificial illuminance (students' tables and writing board)	≥ 500 lux	≥ 300 lux	≥ 200 lux	If other quality levels cannot be achieved

Table 2: Summary of IEQ in schools using the data from the French National schools 'survey (308 schools in total)

Parameter	Category I	Category II	Category III	Category IV	Missing data
Overall classification (TAIL)	**0**	**0**	**5**	**303**	**0**
Thermal environment (T)	**13**	**32**	**102**	**158**	**3**
Air temperature	13	32	102	158	3
Acoustic environment (A)	**89**	**99**	**57**	**49**	**14**
Background noise level	89	99	57	49	14
Indoor air quality (I)	**0**	**5**	**16**	**287**	**0**
Relative humidity	44	155	87	19	3
CO_2	3	25	67	213	0
Benzene	247	53	0	3	5
Formaldehyde	237	71	0	0	0
$PM_{2.5}$	1	68	0	233	6
NO_2	200	67	0	40	1
Visible mould	290	17	0	0	1
Lighting environment (L)	**1**	**56**	**97**	**151**	**3**
Artificial lighting	1	56	97	151	3

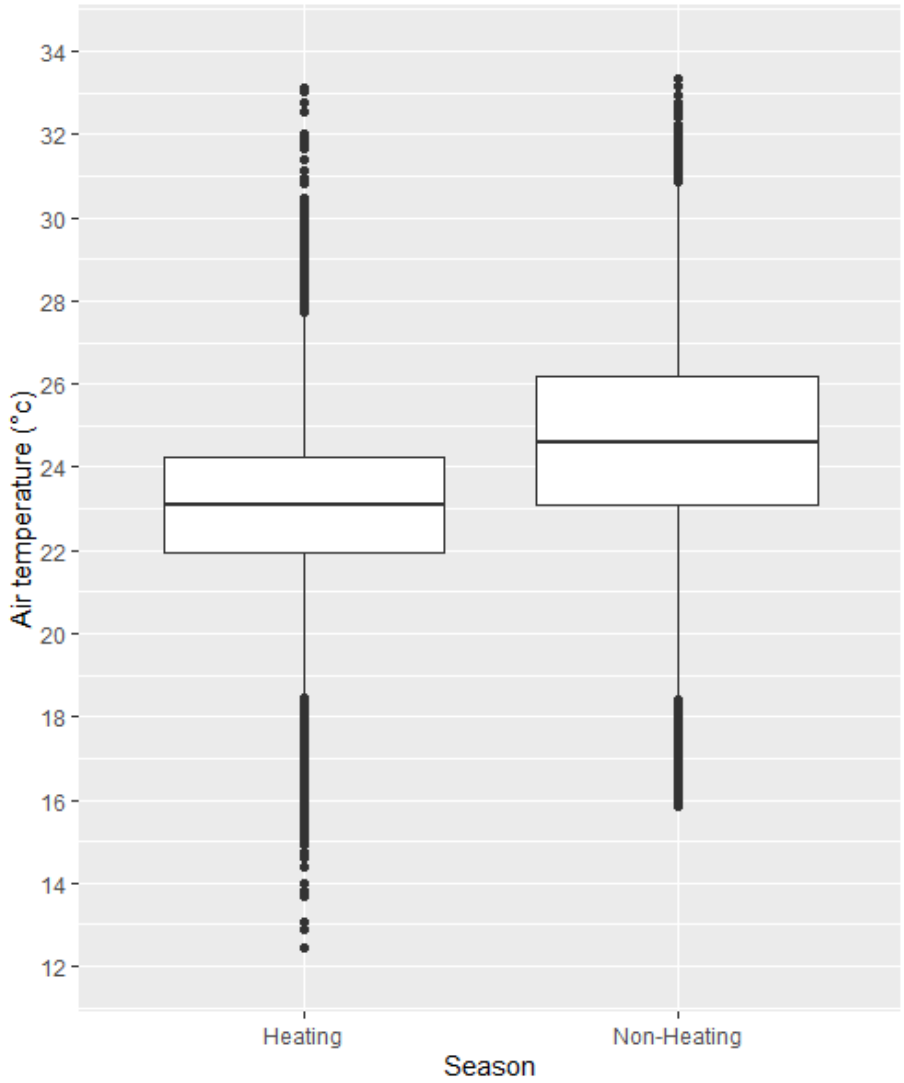

Figure 1: Distribution of the measured air temperatures in schools during the heating season (237 schools) and non-heating season (68 schools)

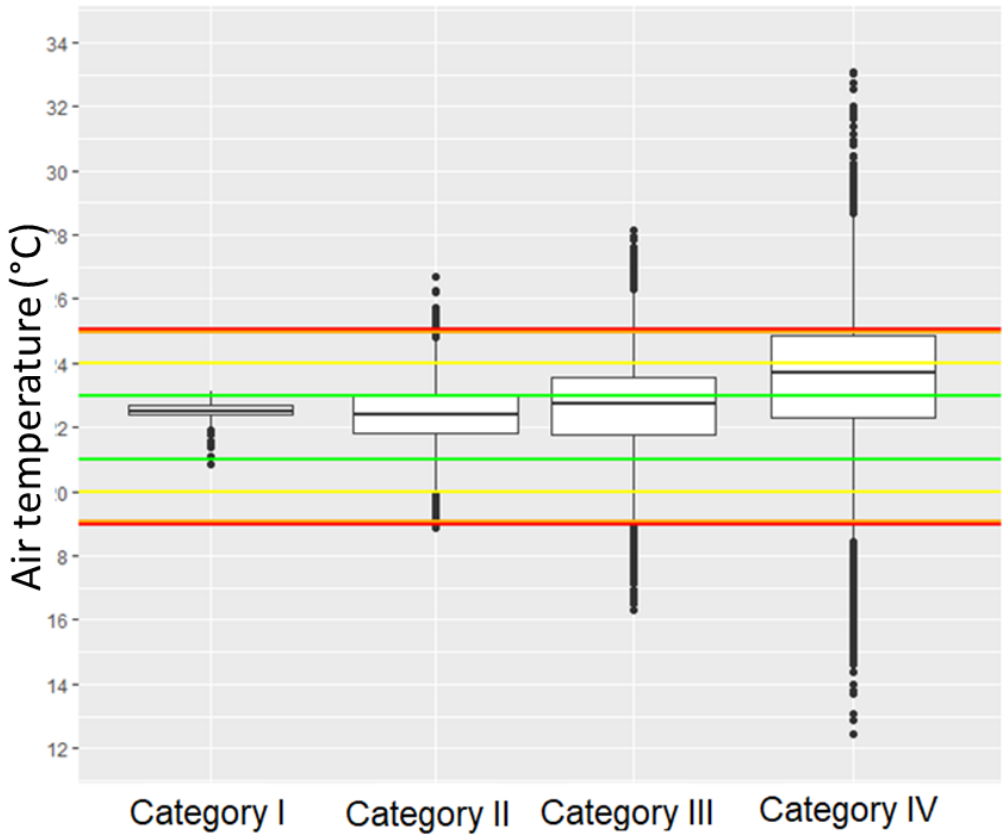

Figure 2: Distribution of measured air temperature during the heating season (237 schools) depending on the categories defined in the TAIL rating scheme

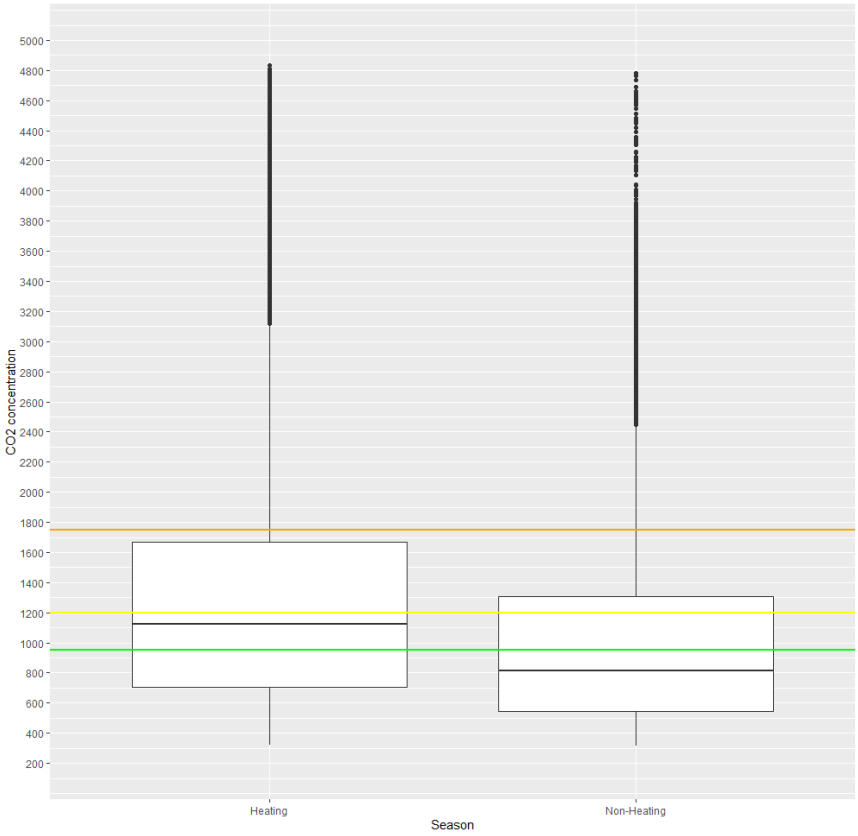

Figure 3: Distribution of measured CO_2 concentrations in schools during the heating season (238 schools) and non-heating season (70 schools)

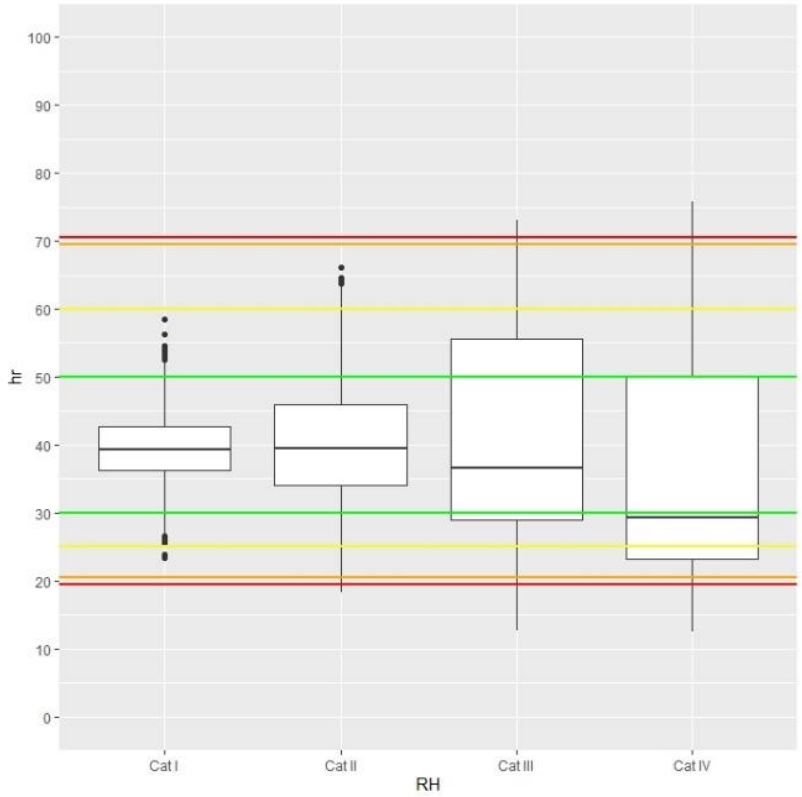

Figure 4: Distribution of measured relative humidity in schools during the heating season (237 schools) depending on the categories defined in the TAIL rating scheme

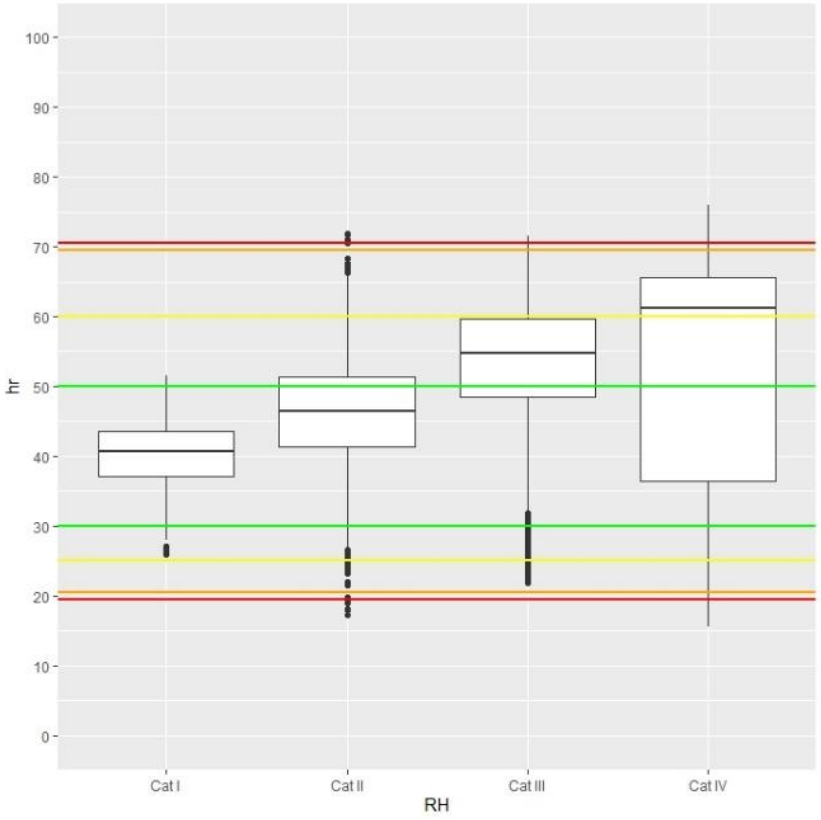

Figure 5: Distribution of the measured relative humidity in schools during the non-heating season (68 schools)

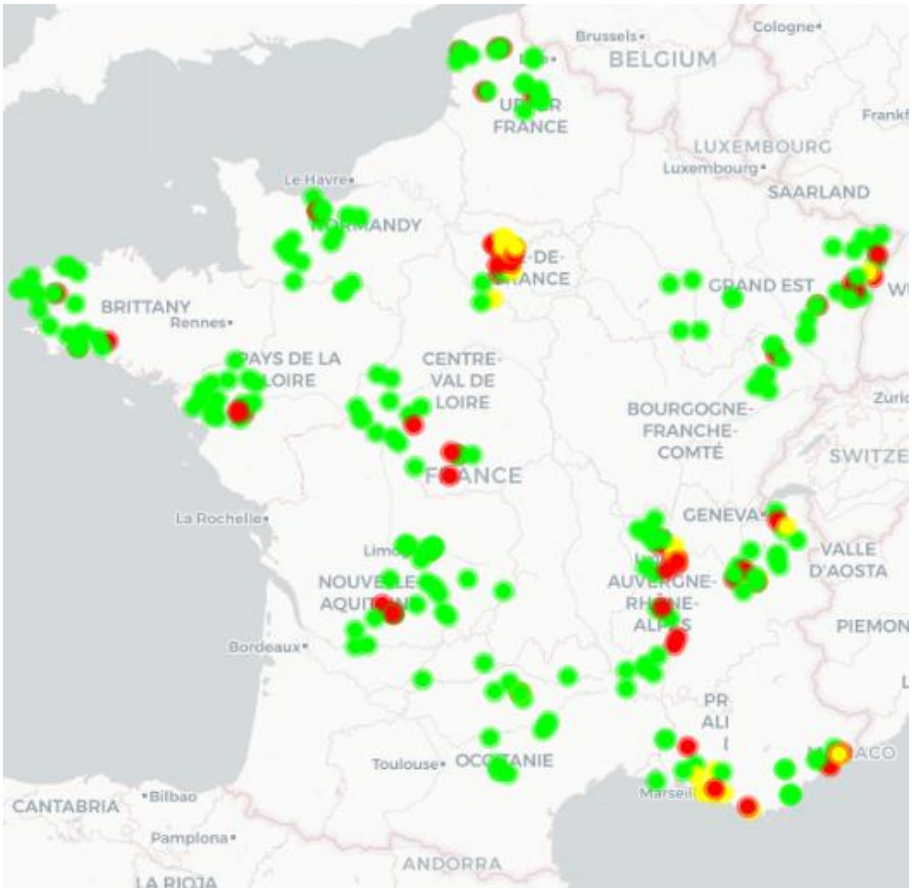

Figure 6: Schools and their corresponding color quality of the measured NO_2 concentration

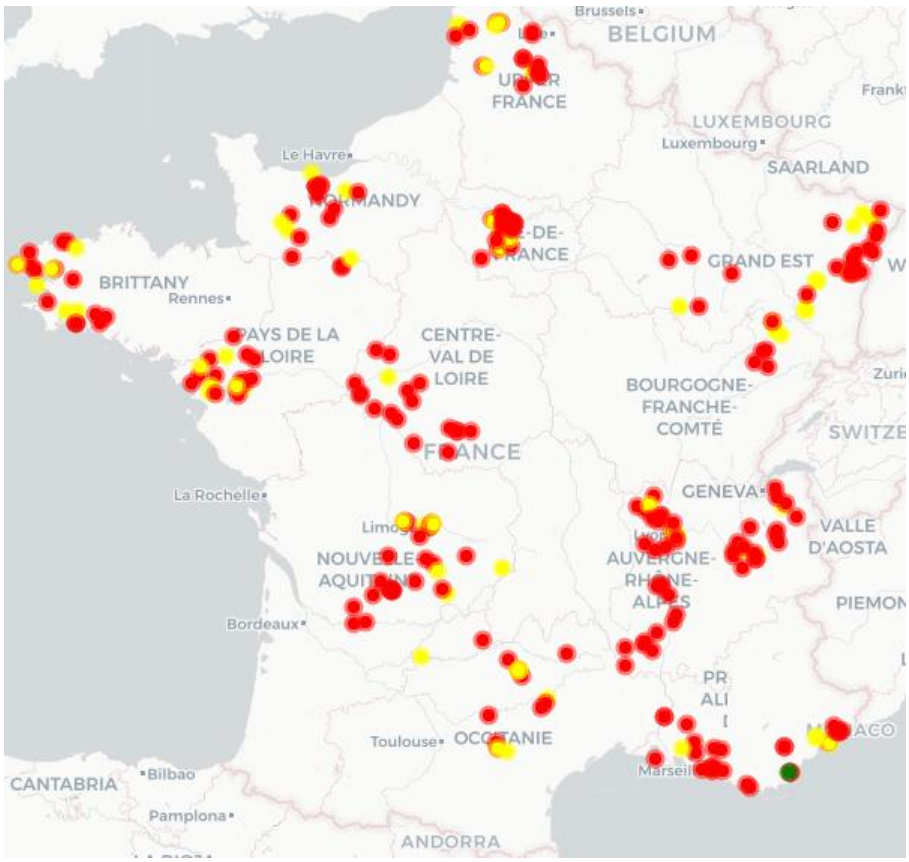

Figure 7: Schools and their corresponding colored quality of the measured $PM_{2.5}$ concentration

3 CONCLUSIONS

The article presents the application of the TAIL rating scheme for schools using the French national survey data. From its initial development for hotels and offices, two new parameters have been added to the scheme: RT and NO2 concentration. The reference values for different quality levels were also updated following the new AQ Guidelines by WHO. The rating scheme was shown to discriminate schools based on their overall IEQ level and specific level corresponding to the thermal, acoustic, visual environment, and indoor air quality Analyses underlined trends, which can aid the decisions made by schools' administrations regarding IEQ improvement. There is clear evidence that the current state of IEQ is unsatisfactory. The TAIL also shows that to achieve high IEQ, no compromises should be made regarding quality levels of parameters defying IEQ. Further analyses will examine the relationship between the obtained IEQ levels defined by TAIL, building characteristics, and occupants' perceptions. A diagnostic plan can then be established, and as a result, further aiding schools in improving IEQ on their premises.

4 REFERENCES

[1] P. Wargocki *et al.*, "TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project)," *Energy Build.*, vol. 244, 2021, doi: 10.1016/j.enbuild.2021.111029.

[2] F. Amato *et al.*, "Sources of indoor and outdoor PM2.5 concentrations in primary schools," *Sci. Total Environ.*, vol. 490, pp. 757–765, 2014, doi: 10.1016/j.scitotenv.2014.05.051.