Sleep characterization of university students: the influence of indoor air quality

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ABSTRACT

Sleep is a crucial aspect of the human daily life. It allows us to recover from physical and psychological fatigue and its lack can bring several consequences to human health. People spend around 1/3 of their life sleeping but despite that, their exposure to pollutants during sleep is often neglected and the studies that try to find how the air quality influences sleep are even scarcer. Upon entering university, students usually change their habits, including their sleep patterns, due to the freedom that they are allowed, which not only puts their health in jeopardy, but their academic performance as well. This study aims to assess the air quality that university students are exposed to in their sleeping environment and how it affects their sleep quality. Firstly, a sleep questionnaire was developed, to characterize sleep habits and sleep quality of the Portuguese population. This anonymous questionnaire comprised four sleep tests (the Pittsburgh Sleep Quality Index, the SATED scale, the sort version of the Functional Outcomes of the Sleep Questionnaire and the Munich Chronotype Questionnaire), a sleepiness scale and questions that characterize the individuals and their sleeping environment. Students were one of the classes with worse results on the tests: only 31% had good sleep quality according to the PSQI and only 62% showed good sleep health, as measured by the SATED scale. After that, 13 university students living in university dorms were monitored during their sleep through actigraphy for two nights. In both nights the air quality of the room was monitored through sensors. The mean concentrations of carbon dioxide (CO_2) and volatile organic compounds (VOCs) surpassed the limit values and double rooms had worse air quality than single ones. CO_2 concentration and relative humidity (HR) correlated negatively with perceived sleep quality (PSQ) (ρ=-0.560 and ρ=-0.527, respectively) and increased with total sleep time (TST). Room temperature correlated negatively with TST (ρ=-0.387).

Keywords: sleep, indoor air quality, college students, Portugal

1. Introduction

Since the classical antiquity that there is a notion of the importance of indoor air quality (IAQ), however, until the second half of the 20th century, the studies that assessed this theme were scarce. With the insurgence of the modern hygiene, in the 19th century, the scientific community started acknowledging environmental problems such as the quality of drinking water and the treatment of the sewage. Despite this, IAQ was still not considered an environmental problem (Sundell, 2004). Only after problems such as contaminations of radon in the late 60's, contaminations of formaldehyde in the early 70's and the insurgence of the sick building syndrome (SBS) later in the same decade, IAQ was finally started to be acknowledged as a major environmental problem (Sundell, 2004).

During the past two decades, IAQ has been the subject of several studies, focusing on the most different microenvironments, such as offices (Wolkoff, 2018b, 2018a), restaurants (Lee et al., 2001) and schools (Daisey, Angell and Apte, 2003). However, there are not many studies that focus on a particularly important microenvironment: the sleep environment.

People spend around one third of their life sleeping, and they stay for a long period of consecutive time on their bedroom while doing so, which aggravates the exposure to pollutants, even if their concentrations aren't as high as in other environments (Canha et al., 2017).

There are even fewer studies that try to relate the IAQ that people are exposed to during sleep and their sleep quality (Strøm-Tejsen *et al.*, 2016; Mishra *et al.*, 2018), with most of the studies that address these problems focusing only on comfort parameters, like temperature and relative humidity (Okamoto-Mizuno et al., 1999, 2004; Lan et al., 2014; Sewitch et al., 1986).

Sleep plays a crucial role on the human daily life. It allows our body (mainly our brain) to recover from the fatigue accumulated throughout the day. It is mainly regulated by three processes: a homeostatic process, a circadian process, and an ultradian process (Borbély and Achermann, 1999). The homeostatic process regulates sleep propensity, rising when awake and declining while asleep. The ultradian process occurs during sleep and it is represented by the variance of REM and non-REM sleep. The circadian process is a clock like mechanism that is independent from prior sleep and determines the variance of periods with high and low sleep propensity (Borbély and Achermann, 1999). The circadian process is related to solar light and the preference for more active periods during light or dark phases, which is what is called the chronotype.

Despite being regulated by natural processes, several external factors can alter the natural process of sleep. Whether it is work obligations and social life (Roenneberg et al., 2003) or the consumption of caffeine (Czeisler, 2013), health problems (Foley *et al.*, 2004) and the use of technological devices, such as mobile phones and laptops prior to sleep (Mohammadbeigi et al., 2016; Demirci et al., 2015). However, one of the factors that affects sleep the most is the one that brought the modern world to where it is now: artificial light. It affects not only the circadian cycle, but also the routines and obligations, by allowing us to be active during the night (Czeisler, 2013).

Another factor that has been shown to have some influence in sleep quality is IAQ. Strøm-Tejsen et al. (2016) studied the effect of different ventilation settings on the IAQ of student dormitory bedrooms, as well as its influence on the students' sleep quality. CO_2 levels were lower with the bedroom window open, which promoted improvement of the sleep quality, perceived freshness of bedroom air, next-day sleepiness and performance of the students. Mishra et al. (2018) also monitored young adults' sleep while changing ventilation settings by opening windows or doors. CO_2 levels ant temperature were lower for the open setting. Like in the previous study, when CO_2 levels were lower, sleep quality, perception of air quality and next-day performance were improved.

Temperature (Ta) is also a major factor in sleep regulation. Exposure to unacceptable heat during sleep can increase wakefulness and reduce REM and slow wave sleep (Okamoto-Mizuno and Mizuno, 2012). The effect is aggravated when coupled with high relative humidity (RH), which is the ratio of water vapor in the air and the saturation point (Okamoto-Mizuno et al., 1999).

Upon entering university, students experience a newly found freedom. This freedom, coupled with demands from social and academic life, often leads to a change in their daily habits. Among those habits are the sleeping patterns (Pilcher et al., 1997). Whether it is for partying or studying, students tend to change the amount of sleep that they get, as well their sleep timing. This occurs in highly demanding stage of their lives, from an intellectual point of view, and leads to several sleeping problems (Buboltz, Brown and Soper, 2001; Lund *et al.*, 2010).

So, this work aims to provide an overview of the sleep quality of the Portuguese population and, taking in account the importance of this population group, the influence of IAQ on university students' sleep. For the latter, students housed in university dorms at Lisbon (Portugal) were selected, since they provide a sample with similar conditions, and the ability to study factors such as room occupation and ventilation for the same external conditions.

2. Materials and methods

2.1. Study sites and participants' characterization

Firstly, a sleep questionnaire was developed. This questionnaire comprised four sleep tests: the Pittsburgh Sleep Quality Index (PSQI), which assesses sleep quality, the SATED scale, that assesses sleep health (both of these tests were previously validated for the Portuguese population (Del Rio João *et al.*, 2017; Martins, 2017)), the short version of the Functional Outcomes of the Sleep Questionnaire (FOSQ-10) to check the alertness, and the Munich Chronotype Questionnaire (MCTQ)) to assess the difference of sleep timing on working and resting days (social jet-lag), a daily sleepiness scale and several questions to characterize their individual life-style and their perception of the sleeping environment. It was distributed online to all the population and answered anonymously. The objective was to verify which social and environmental conditions affected sleep the most and how students were placed among the general Portuguese population. The questionnaire got 1040 answers and the respondents are characterized in Table 1.

The results of the tests were then grouped by several factors regarding the personal context (sex, age, professional occupation, school level, practice of physical activity and presence of cardiorespiratory problems) and the sleeping environment (light, noise, perceived IAQ and room occupation).

Two student dormitories were selected and 13 students from both dorms agreed to take part in the study. Residence A is located on the outskirts of Lisbon and it is functioning since 1998. It is composed by three blocks: A, B, and C, with 3 floors each. It has 189 bedrooms, from which 153 are single bedrooms and 36 are double bedrooms. The single bedrooms have 11.2 m^2 of area while the doubles have 15.3 m^2. Residence B is located in a technological and business park near Lisbon and it is functioning since 2013. It has only one block, with 66 single bedrooms and 8 double bedrooms. The single bedrooms have 13.4 m^2 of area while the doubles have 16.7 m^2.

In residence B, all bedrooms have mechanical ventilation (MV) whereas in residence A only block C has this mechanism. All bedrooms in both residences have access to natural ventilation (NV) through a window. In both residences MV is obtained through a fan placed in the bathrooms, which are inside the bedrooms and it is not manually controlled. In residence A it is programmed to work between 7h and 10h in the morning and 18h and 22h in the evening, while on residence B it is turned on between 8h and 11h in the morning and 19h and 22h in the evening.

The characterization of the participants in this study is summarized in Table 2.

Table 1. Characterization of the respondents

Characteristics	n	%	Characteristics	n	%
Sex			*Professional occupation*		
Male	335	32	Student	304	29
Female	705	68	Unemplyed	20	1.9
			Employer	77	7.4
			Employee	614	59
Age group			Retired	9	0.9
18-20	123	12	Fellow	8	0,8
21-25	227	22	Working student	8	0.8
26-30	111	11			
31-35	114	11			
36-40	167	16	*School level*		
41-45	109	10	Middle school	19	1.8
46-50	72	6.9	High school	273	26
51-55	49	4.7	Technical school	43	4.1
56-60	44	4.2	Licenciate’s degree	428	41
>60	24	2.3	Master’s degree	216	21
			PhD	61	5.9

2.2. Sleep monitoring

Wrist actigraphy was used to monitor students’ activity levels during two consecutive days, in order to estimate sleep quality and sleep time. This is a well validated method for estimation of sleep parameters (Martin and Hakim, 2011). It registers the physical activity of the subject and calculates a sleep score based on computer models. It is not a substitute of methods like polysomnography or sleep logs but it is a good complementary method. It was used an actigraphy set by Condor Instruments. The actigraph ActTrust registers movement levels according to the proportional integration mode (PIM), the time above threshold mode (TAT) and the zero crossings mode (ZCM) as well as other factors such as temperature. Then the software ActStudio estimates the sleeping score according to the data registered by the actigraph. To complement the information provided by the

Table 2. Charaterization of the participants, where S stands for single bedroom, D for double bedroom, N for Natural Ventilation and M for mechanical and natural ventilation.

Subject	Age	Sex	Height (m)	Weight (kg)	Medication	Residence	Block	Bedroom type	Ventilation
1	21	Female	1.57	48	No	A	A	S	N
2	19	Male	1.87	75	No	A	A	D	N
3	19	Male	1.8	70	No	A	A	S	N
4	24	Male	1.62	62	No	A	A	D	N
5	24	Female	1.58	55	No	A	A	D	N
6	18	Female	1.74	67	Arthrotec	A	C	D	M
7	18	Male	1.81	70	No	A	C	D	M
8	19	Female	1.61	52	Minesse	A	C	D	M
9	19	Male	1.75	60	No	A	C	D	M
10	19	Female	1.62	62	No	B	-	S	M
11	18	Male	1.62	53	No	B	-	S	M
12	19	Female	1.65	50	No	B	-	S	M
13	20	Male	1.82	73	No	B	-	S	M

actigraphy, the students were asked to fulfill a sleep diary where they registered what time they went to bed, when they turned out the lights to sleep, woke up, had breakfast, how well they slept the previous night, how many times did they woke up and other aspects about their day.

2.3. Indoor air quality monitoring

The IAQ of the bedrooms was monitored during two consecutive sleeping periods, corresponding to the days when sleep was being monitored as well. For that, a monitoring box was used to measure the levels of CO_2, volatile organic compounds (VOCs), and particulate matter with aerodynamic diameter lower than 2.5 µm ($PM_{2.5}$) and lower than 10 µm (PM_{10}). Ta and RH were also monitored by the box.

The monitoring box is equipped with several sensors:

- SCD30 for CO_2 detection (range: 400 to 10000 ppm);
- SHT31 for measurement of T and RH (typical precision: ±2 % RH and ± 0.3 °C);
- MiCS-VZ-89TE for VOCs detection (range: 0 – 1000 ppb in isobutylene); and
- HPMA115S0 to measure $PM_{2.5}$ and PM_{10} (range: 0 – 1000 µg.m^{-3}).

2.4. Statistical analysis

Analysis of data was conducted by applying statistics with a significance level of 0.050.

Sleep parameters were correlated between them using Spearman's test. The same procedure was taken to assess the correlation between sleep and IAQ parameters.

Regarding IAQ data, statistical difference between two independent samples (e.g. double or single rooms) was assessed using the Mann-Whitney's test.

All statistical analyses were performed using IBM SPSS Statistics 23 software.

3. Results and discussion

3.1. Sleep questionnaire

Figure 1 shows the overall results of all population on the sleep tests.

It is possible to observe that there was a large part of the population that presented sleep disorders. In PSQI, only 40.1% of the population scored "good" for sleep quality (<5), while 8% scored a value above 10, which indicates the presence of a sleep disturbance. More than half (51.9%) of the population scored between 5 and 10, which means they had a poor sleep quality. In the SATED scale, 67.9% of the respondents scored good sleep health, however the amount of people with sleep health scores in the average range (4 to 6) was almost a third of the population (31.1%). A similar situation happened in the FOSQ-10 results where 63.3% of the respondents scored a high alertness state (>15) and close to 30% in the average range ([11-15]). However, 7.2% of the respondents scored a low alertness state (score from 5 to 10). In the MCTQ results it is possible to observe that 50.8% of the

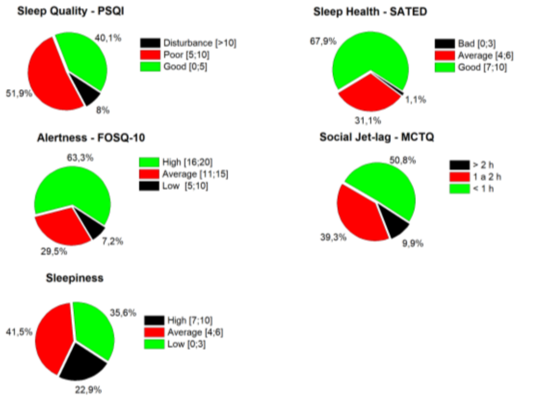

Figure 1. General results of the sleep tests

population did not offset their sleep by more than one hour. This shows that close to 50% of the population did not sleep in their preferred timing during working days. Regarding the sleepiness, only 35.6% report a daily sleepiness below 4 in a 0 to 10 scale. The majority (41.5%) reported a sleepiness between 4 and 6 during daytime and an alarming 22.9% report a score above 6.

One of the main points of interest is the professional occupation of the respondents and its influence on their sleep quality, as shown in Figure 2.

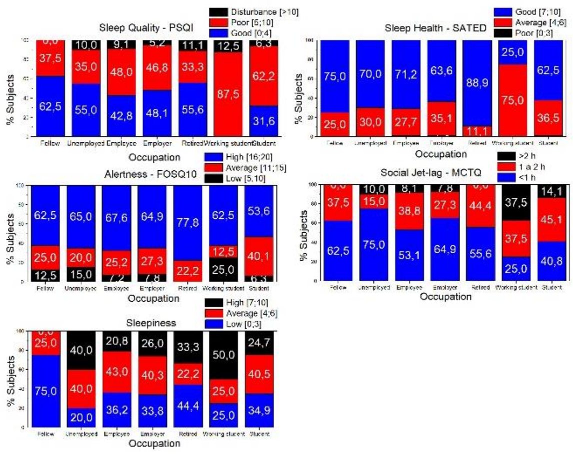

Figure 2. Influence of the professional occupation of the respondents on the resutls of sleep tests

It is noticeable that students (working students in particular) scored the worst results in every test. No working student scored a good sleep quality, according to PSQI, and 12.5% of them scored more than 10, which indicates the presence of a sleep disturbance. In the same test, only 31.6% of the students presented a good sleep quality and 62.2% scored for poor sleep quality. In the SATED scale, only 25% of the working students score a good sleep health while the remaining 75% scored from 4 to 6. Excluding this group, students and employers have the worst results in this test. 63.6% and 62.5% of the employers and students respectively scored good sleep health, with the remaining 35.1% and 36.5% scoring between 4 and 6. In FOSQ-10, an alarming 25% of the working students had a low alertness state. Students were the ones with the lowest proportional of people with a high alertness state (53.6%). Only 25% of the working students did not offset their sleep by more than one hour on rest days than in working days, while 37.5% did it more than two hours and the remaining 37.5% between one and two hours. Excluding this group, students were the ones who scored worse, with only 40.8% having a difference smaller than one hour between rest and working days, while 45.1% of them had a difference between one and two hours and 14.1% bigger than two hours: the higher proportions of people in these ranges from any group. In the sleepiness scale, students do not stand out from the other occupations, as opposed to working students from whom 50% reported a high daily sleepiness and 25% in each of the remaining categories. On the upside, 75% of the fellows reported low sleepiness and the remaining 25% were in the average range. None of them reported high sleepiness.

Another interesting factor is the influence of having other people in the same bedroom, whether sleeping on the same bed or in separate beds. Figure 3 presents the influence of having another person in the bedroom, while sleeping, in the sleep tests.

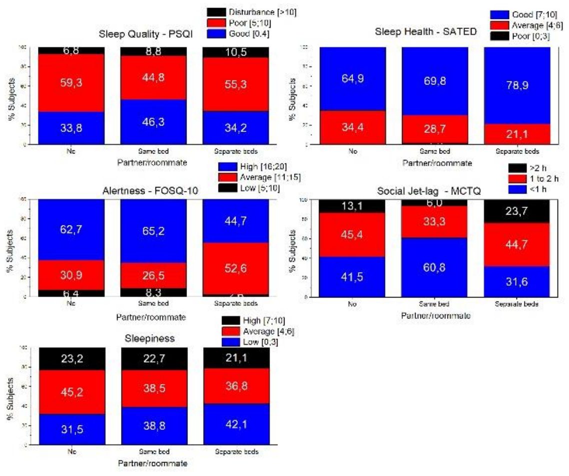

Figure 3. Influence of the room occupancy in the results of the sleep tests

Looking at these results, a clear relationship between room occupancy and better results on the tests was not found. In the PSQI, people who have a partner in the same bed indicated better results: 46.3% of them had good sleep quality, while 44.6% were in the average range. In the SATED scale, the ones with better results were the ones who had roommates (on separate beds), where 78.9% scored a good sleep health and the remaining 21.1% on the average range. On the other hand, this was the group with the smallest proportion of people with high alertness status, as measured by the FOSQ10, being the only group with less than 50% of people in this range (44.7%). They were also the group with more people on the average range (11 to 15). The other two scored similar results: around 65% with high alertness and around 30% in the average range. In the MCTQ, people who share the bed stand out the most, being the only ones with more than half of the people with less than one hour of social jetlag (60.8%). They were also the ones with the smallest portions on the other two ranges, with 33.3% in the medium range and only 6% having a difference of more than two hours of sleep between working and resting days. Regarding sleepiness, the ones with worse results are the people who sleep alone in the bedroom. 31.5% of them reported low sleepiness, opposed to 38.8% from the ones with bed partners and 42.1% from the ones with roommates. They were also the ones with the bigger proportion in the average sleepiness range (45.2%) and high sleepiness range (23.2%).

The other major interest factor is the influence of the perceived air quality in the bedroom in the sleep, as shown in Figure 4.

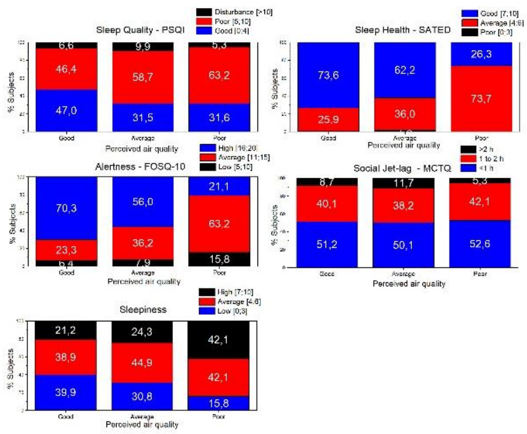

Figure 4. Influence of the perceived air quality on the results of the sleep tests

In all tests, it is possible to observe a decrease in the results with the decrease of air quality, apart from the MCTQ. In the PSQI, people who reported good IAQ were the ones with the biggest parcel with good sleep quality (47.0%) and the ones with the smallest parcel in the average range (46.4%). In the SATED scale, there was an inversion of the results between people that reported good IAQ and the ones that reported

Table 5. Descriptive analysis of pollutants and comfort parameters during the sleep periods in the 13 bedrooms. n represents the percentage of time that the limit values were surpassed

	Pollutants				Comfort parameters	
	$PM_{2.5}$ (µg.m^{-3})	PM_{10} (µg.m^{-3})	CO_2 (mg.m^{-3})	VOC (µg.m^{-3})	Ta (°C)	RH (%)
LV	25	50	2250	600	[23;26]	[30;70]
$\bar{x} \pm \sigma$	7.96 ± 3.97	9.14 ± 4.85	3270 ± 1980	864 ± 269	24.0 ± 1.26	56.8 ± 9.63
[Min-Max]	[1.19-61.8]	[1.44-71.1]	[452-12800]	[422-2280]	[21.42-27.0]	[32.0-82.0]
Med	5.23	6.08	2660	780	23.5	58.2
n (%)	0.62	0.09	65.8	92.4	24.2	39.1

poor IAQ: 73.6% of people that reported good IAQ had good sleep health and 25.9% had poor sleep health, while 26.3% of people who reported poor IAQ had good sleep health and 73.7% had average sleep health. A similar case happened in the FOSQ-10: 70.3% of the people that reported good IAQ scored a high alertness status, 23.3% an average alertness status and only 6.9% a low alertness status. On the other hand, only 21.1% of the ones with poor IAQ had a high alertness status, 63.2% of them were on the average range and 15.8% had low alertness status. In the MCTQ, there was not a clear influence of IAQ since all the groups had close to 50% of the people with less than one hour of social jetlag and around 40% with a jetlag between one and two hours. In the daily sleepiness, the influence of IAQ showed again, with an inversion found as happened with the SATED scale and the FOSQ-10.

3.2. Sleep monitoring

Using sleep diaries and actigraphy data, it was possible to obtain information about several sleep parameters, namely the total sleep time (TST), perceived sleep quality (PSQ) and number of awakenings (NA). Table 3 shows the results of these parameters for each sleep period. Due to the loss of data by the subject 5, this subject was not considered in the sleep monitoring results. The same happened to the second night of subjects 6 and 9.

Students slept, on average, 7h30min per night. However, it is possible to see great deviations from this value. Some examples that stand out are the first night of subject 8, where she slept 10h15min, and the second night of subject 11, where he only slept 3h3min. Despite the mean value being on the adequate range for an adult (between 7 and 8 hours), there are high discrepancies between subjects, which is to be expected considering Pilcher *et al.* (1997) that studied sleep quality in university students. Regarding PSQ, a mean value of 6.9 was found, however also with high deviations, namely the second night of subject 4 (10) and the first night of subject 7 (3.5).

Table 1. Sleep parameters of each sleep period, where S stands for subject and N for night studied.

Subject/Night	TST (h)	PSQ	NA
*S*1 N1	08:20	8	1
*S*1 N2	07:25	8	1
*S*2 N1	10:15	5	2
*S*2 N2	09:00	5	4
*S*3 N1	07:30	7	0
*S*3 N2	07:30	7	1
*S*4 N1	06:00	9	0
*S*4 N2	06:18	10	0
*S*6 N1	07:30	6	-
*S*7 N1	05:55	3.5	3
*S*7 N2	07:10	6	1
*S*8 N1	10:15	9	0
*S*8 N2	09:25	7	0
*S*9 N1	07:35	7	1
*S*10 N1	08:27	6	3
*S*10 N2	07:50	5	2
*S*11 N1	05:50	7	3
*S*11 N2	03:30	9	1
*S*13 N1	07:25	7	1
*S*13 N2	06:50	7	2
$\bar{x} \pm \sigma$	7:30 ± 1:30	6.9 ± 1.6	1.4 ± 1.2
[Min-Max]	[3:30-10:15]	[3.5-10]	[0-4]
Med	7:30	7	1

To see how these parameters correlate between them and with the activity levels measured by actigraphy, it was constructed a correlation matrix using Spearman's test, as shown in Table 5

The activity levels were represented by the PIM since it is the mode that better correlate with polysomnography (Blackwell *et al.*, 2008).

Table 2. Correlation between sleep parameters
*bold values indicate significant correlations ($p<0.050$)

	TST	PSQ	NA	PIM
TST	1	-0.254	0.003	0.064
QS_p		1	**-0.712**	-0.146
NA			1	**0.338**
PIM				1

As it was expected, there was a strong negative association between QS_p and NA. Besides this, NA shows a moderate positive association with PIM, which is also to be expected since PIM refers to movement, which is more accentuated when awake.

3.3. Indoor air quality monitoring

IAQ monitoring was carried out during two consecutive sleeping periods for each student.

Table 5 shows the average, standard deviation, minimum, maximum, median and the compliance with the limit values (LV) established in the te Portuguese legislation (Ordinance n.º 323-A/2013 (2013)) for CO_2, VOCs and PM and in ISO 7730 (2005) for Ta and RH.

On average, levels of $PM_{2.5}$ and PM_{10} were below their LV. The same did not happen for CO_2 and VOCs, with their mean values (3270 ± 1980 mg.m^{-3} and 864 ± 269 µg.m^{-3}, respectively) above the LV of 2250 mg.m^{-3} and 600 µg.m^{-3}, respectively. This is mainly due to poor ventilation because CO_2 and COVs accumulate during the night (Bekö *et al.*, 2010) since these pollutants are exhaled by the occupants during their sleep (Wanner, 1993; Phillips *et al.*, 1999).

CO_2 is known to be a cognitive inhibitor in humans (Satish *et al.*, 2012) and can cause headaches, discomfort, nausea and eye and throat irritation (Schwarzberg, 1993; Yang, Sun and Sun, 1997). It is important to note that in residence A the mean levels of CO_2 are higher than in residence B (4310±2110 mg.m^{-3} *vs* 2020±629 mg.m^{-3}, respectively) because all the rooms in residence B are single and have MV. VOCs are highly irritating to the eyes and respiratory tracts (WHO, 2008) as well as can damage organs such as liver and kidneys and cause cancer (Barn, 2013).

The comfort parameters are also, on average, inside their comfort range, however, these ranges are crossed 24.2% of the times for Ta and 39.1% for RH, which can potentiate the growth of microbial contaminants (Arundel *et al.*, 1986).

To assess the influence of the available ventilation, whether it had MV or not and the influence of having a roommate it was used Mann-Whitney's test (U). In double rooms, the levels of CO_2 (3360 ± 2360 mg.m^{-3}), VOCs (962 ± 397 µg.m^{-3}) and RH (58.3 ± 8.42%) are significantly higher than in single rooms (1790 ± 754 mg.m^{-3}, 638 ± 137 µg.m^{-3} and 47.5 ± 8.37% respectively), with a significance level of 0.050. This is to be expected since the main source of these contaminants in the bedroom is the human breath.

Regarding the ventilation settings, initially none of the parameters varied significantly with the availability of MV. However, eliminating the influence of the occupancy and only considering double rooms, VOC levels were significantly higher in the rooms with MV (1110 ± 260 µg.m^{-3} *versus* 894 ± 184 µg.m^{-3}). The lack of influence of MV in the remaining parameters is probably due to the timing and low frequency that is activated, as well as its location, since it is located in the bathrooms and not directly where the occupants sleep.

3.4. Influence of indoor air quality on sleep

To assess the influence of IAQ on sleep quality a new correlation matrix was build using Spearman's test (Table 6).

Both $PM_{2.5}$ and PM_{10} showed a positive association with activity levels (PIM), which is to be expected because movement during sleep promotes the resuspension of particles that were previously settled in the bed clothing and mattress (Canha *et al.*, 2017).

Table 6. Correlation between IAQ and sleep parameters

		QS			
		TST	PQS	NA	PIM
IAQ	$PM_{2.5}$	0.260	-0.171	-0.001	**0.387**
	PM_{10}	0.260	-0.171	-0.001	**0.387**
	CO_2	**0.497**	**-0.560**	0.224	-0.267
	VOC	0.072	-0.290	-0.171	-0.123
	Ta	**-0.381**	0.115	-0.143	-0.099
	RH	**0.671**	**-0.527**	0.170	-0.042

*bold values represent significant association (p<0.050)

CO_2 and RH show positive associations with TST. This is because their primal source in this environment is the occupants' breath and so, the longer people sleep, the longer they are exhaling CO_2 and water vapor. However, these two also show negative associations with PSQ confirming the previous findings that CO_2 and RH have a negative effect on sleep. (Okamoto-Mizuno, Tsuzuki and Mizuno, 1999; Strøm-Tejsen *et al.*, 2016; Mishra *et al.*, 2018). Ta shows a negative association with TST, which is also in accordance with the previous literature that reports Ta to affect the duration of REM sleep and increases wakefulness (Okamoto-Mizuno and Mizuno, 2012; Urlaub *et al.*, 2015).

4. Conclusions

This work provided new and relevant information about sleep quality and sleep problems in the Portuguese population, specifically in university students.

It also reinforced the previous findings that IAQ affects sleep quality, and thus, has a bigger impact on human health and well-being that one might think at first.

This study concludes that a large amount of the Portuguese population has poor sleep quality. This is shown by the fact that only less than half (40.1%) of the 1040 respondents of the questionnaire got a good sleep quality, as measured by PSQI and almost a third of the respondents (32.2%) reported not having a good sleep health according to the SATED scale. Also, only 50% of the people slept in their preferred timing during working days according to the MCTQ, 36.7% did not have a high alertness state during the day, as measured by the FOSQ-10, and only 35.6% reported low sleepiness during the day.

University students stand out from the rest of the population, obtaining worse scores in almost every test when compared to other professional occupations. The students whose sleep was monitored showed highly irregular sleep patterns between them, evidencing the lack of sleep quality reported by the 312 students and working students that answered the online questionnaire.

In the studied university dormitories, it was found an accumulation of pollutants and contaminants, such a CO_2 and VOCs, that can reach and even surpass their respective limit values. This can have a negative effect on the occupants' health according to previous studies that show the effects of these compounds on human health and well-being. This is particularly concerning for double rooms that showed significantly higher levels of CO_2, VOCs and RH. As opposed to the expected, MV did not show a positive effect on IAQ, probably due to the low frequency that it is activated.

To improve IAQ in the bedrooms, the residences should install MV in all bedrooms and activate it with more frequency. One solution can be the installation of an inaudible fan that is activated during the night.

Another option is to make all bedrooms to be single, or, for future projects, make bigger rooms in order to dilute the pollutants and, thus, to reduce the exposure of its occupants to poor IAQ.

This study also corroborates previous works that state the negative influence of poor IAQ on sleep quality. CO_2 and RH levels increased with TST and showed a negative effect on PSQ, while Ta had a negative effect on TST. PM related positively with activity levels, since movement promotes resuspension of settled particles.

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