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The influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units

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ABSTRACT

The present study aimed to investigate the risk of symptomatological complaints resulting from exposure to indoor environmental quality variables in intensive care units (ICUs) and to determine the exposure risk caused by the interaction of these variables. Nine ICUs in the city of João Pessoa/Brazil, were selected, and for three consecutive days, temperature, noise, lighting and air quality measurements were collected. Simultaneously, 128 professionals were interviewed to assess their perceptions of, satisfaction with and health conditions associated with the environment. The risk of exposure to adverse environmental conditions was estimated using Bayesian networks and validated according to the predictive values and the area under the Receiver Operating-Characteristic curve. The results indicated that the ICUs were at the limits of the hygienic standards stipulated for the sector; employees working had a 42.2% probability of experiencing physical symptoms associated with environmental discomfort and a 45.3% probability of experiencing psychological symptoms associated with environmental discomfort, representing increases of 24.5% and 6.9%, respectively, above the basal probability. The variables with the highest impact on the health of professionals were temperature variables, which were estimated using the average rating predicted by ISO 7730/2005 and self-reported perceptual variables. The interaction between environmental attributes in a risk scenario indicated that the environmental temperature could affect other environmental variables that impact the health of professionals. Hence, the risk arising from an uncomfortable environment is not simply the sum of the individual risks for each attribute; rather, it is the result of synergy between the measurable and perceived variables.

1. Introduction

The ICU is a hospital environment designed for the control, maintenance and recovery of vital functions. Patients hospitalized in the ICU have significant and potentially lethal morphofunctional impairments that require highly specialized and intensive human, material and technological investments [5,64].

ICUs arose from the evolution of the complexity of human diseases and have undergone substantial technological, physical and organizational changes throughout the years. Current intensive care practices in the ICUs are very different from those that marked the origins of these units. The scientific progress of medicine, the aging of the population and the appearance of multi-resistant organisms has resulted in the need to group a larger number of professionals, develop patient monitoring and life support equipment that are more effective and precise, and create improved, highly specialized pharmaceuticals [35,51,55].

Thus, “intensive medicine is one of the fields showing remarkable progress, in terms of research as well as treatment” [70]. This statement reflects the social importance of this field; as an example, intensive medicine represents approximately 0.66% of the gross domestic product of the United States, generating over $81 billion dollars in expenses per year [24,48]. It is predicted that in the next 10 years, there will be greater investments in this sector, with the consequent implementation of changes in technology and work processes, including the application of computerized data management [35].

The objective of these health services is to provide conditions that are favorable to the patients' healing process [44].

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Nevertheless, both the performance of the work and the intended results can be affected by environmental comfort variables [25] such as lighting, noise, temperature and air quality. It is worth mentioning that environmental stimuli have different repercussions in the body and mind of an individual. Hence, in terms of environmental aspects, unhealthy workplaces can cause several diseases that affect workers' physical and/or mental health [57] and behavioral and social functioning [47].

The influence of occupational environmental variables on human beings includes aspects of quality of life and general health [7] and can even affect cognitive processes [61]. Considering that the work performed in the ICU requires attention, agility and concentration, unfavorable environmental conditions can harm employee health and wellness by inducing such symptoms as headache, irritability and fatigue; are attenuating factors for workplace accidents; and can slow patient recovery by introducing an increased number of number of medical errors [39]. Hence, to perform work tasks efficiently and safely, it is necessary to reach an equilibrium between the workplace environment and the psychophysiological requirements for comfort, which encompasses the perception of and satisfaction with the environment [16,63]. Additionally, it is possible to prevent the harms associated with exposure to physical environmental variables by applying risk stratification and proper environmental control.

Therefore, it is understood that the workplace represents an important quantitative indicator of risk exposure and how professionals are affected by the environmental aspects of comfort [5]. Nevertheless, the effects of exposure are frequently considered separately for each environmental variable; for instance, the effects of lighting on the satisfaction, performance, health and safety of the professional, as verified by Ref. [13]; the evaluation performed by Ref. [2] in relation to temperature-related comfort in hospitals in tropical climates [43]; investigation of the noise level in ICUs; and [20]; investigation of the concentration of suspended particulate matter in Greek hospitals. These studies are highly important; however, when analyzed in isolation, they do not reflect the risk arising from relationships among the variables, bearing in mind that the interaction between environmental attributes is synergic and the articulation of the environmental stimuli could promote broader risks than the simple sum of isolated effects.

Studies to evaluate the consequences of the set of environmental variables professional health were initiated by Ref. [11]; who evaluated environmental comfort in the ICU based on the noise, lighting and air temperature. However, this author did not include the air quality variable. Other authors, such as [27]; who identified professionals' health risks from noise levels, temperature, air humidity and lighting; and [68]; who evaluated the environmental attributes of the ICU and related them to the occupational risk; these authors performed studies focused on the identification of risk exposure from a qualitative categorization in levels (high, medium and low risk), but not from on risk in probabilistic terms.

This finding and the observation that environmental variables can predict the health status of exposed populations have been verified by Ref. [67]; who stated that the prevalence of echocardiographic abnormalities is associated with the long-term exposure to noise, which doubles the incidence of high blood pressure and increased heart rates; by Ref. [69]; who showed that improper lighting was associated with visual fatigue, headaches, sleep disorders and irritability that could be harmful to the health of humans; and by Ref. [65]; who verified the positive relationship between self-reported temperature perceptions and task execution and error rates. These studies have prompted new investigations to determine the probable risk to the health and welfare of ICU professionals that is associated with environmental comfort variables. In this sense, this paper presents a study of the risk associated with each variable individually and with all environmental comfort variables as a group, considering the professionals' perceptions of comfort, health and welfare in acclimatized intensive care units (ICUs).

2. Materials and methods

The methodological procedure began with a literature review, which provided the foundation for the instrumental aspects of data collection and the relevance of the proposed subject. This theoretical framework was structured according to the protocol in *Statement for Reporting Systematic Reviews* (PRISMA) [41].

2.1. Study field and sample

The study was conducted at adult ICUs in the public health system of the city of João Pessoa, State of Paraíba, Brazil (Table 1) between July 20 and August 29, 2015. The selection criterion was selected to maintain the homogeneity of the characteristics in the studied environment, that is, it was chosen so that they were as similar as possible, considering that adult ICUs differ from pediatric ICUs in terms of layout, organization and technological equipment and coverage, given that 68.4% of ICUs in Brazil provide adult care [1].

The analysis units showed heating, ventilation and air conditioning (HVAC), split and centralized types. Centralized HVAC were served by air handling units (AHU) for distribution in hospital specific areas such as ICU and surgical centers. In both cases, the air velocity varied between 0.3 and 0.5 m/s.

The sample included health care professionals (doctors, nurses, physiotherapists and nurse technicians), who formally agreed to participate in the study by signing the Free and Informed Consent Form and who had a minimum workload of six hours in the department.

The investigated professionals have purely assistential assignments, that is, they support the clinical treatment and therefore have similar working characteristics; they are in direct contact with the patient and are continuously in the ICU. The specific attribution of the doctor is the diagnosis and management of the assistance provided in ICU; the nurse's is the continuous and direct care of the patient and receiving and welcoming the patients' family; the physiotherapist's is the rehabilitation of a variety of organic systems; the nurse technician's is the provision of basic care in daily life, such as hygiene, nutrition and medication.

The study procedures were submitted to the Research Ethics Committee of the Center of Health Sciences of the Federal University of Paraíba (Universidade Federal da Paraíba), and were approved on July 1, 2015 under number 1.133.163.

2.2. Studied variables

Measurable data for comfort variables were considered. These variables included temperature, noise, lighting and air quality characteristics, which were classified as "predictor variables"; environmental perception parameters, which were classified as "mediating variables"; and symptomatic complaints related to exposure risk, which were classified as "result variables". The variables were classified to meet the needs of the adopted statistical method and the structure of the designed model.

2.3. Data collection

Measurement logistics were planned in advance according to the architectural design of the studied ICUs and normative orientations. The measurements were performed near patients' beds and at the

Table 1
Characteristics of the analysis units.

	1	2	3	4	5	6	7	8	9
Specialty	Obstetrics	Obstetrics	Trauma-orthopedics	Clinical	Clinical	Cardiology	Clinical	Clinical	Clinical
Dimension (m^2)	140.3	110.2	251.8	112.2	141.6	78	114.7	116.8	116.8
Beds	6	7	18	8	10	6	7	6	7
Professionals[a]	5	8	16	7	8	6	7	10	10
HVAC[b]	Split	Split	central	Split	Split	Split	Split	central	central

[a] per shift.
[b] HVAC = ventilation and air conditioning.

nurse stations and medication preparation rooms (located inside the ICUs) on three consecutive days. Measurements were taken on non-rainy days during the morning, afternoon and night shifts to ensure that the assessments covered the complete work schedule. The collection instruments were calibrated before the measurements.

2.3.1. *Temperature*

The temperature was measured with the *Instrutherm* TGD 400 (precision ± 0.5 °C). Given the minimum adaptation time of 30 min, the device was positioned at previously determined fixed points in the room so that it did not interfere with the mobility of the professionals and was not near doors or windows. Measurements were performed every 1 min according to the recommendations of [31] and [30] measured for eight hours distributed between shifts. To obtain the PMV (Predicted Mean Vote) indexes, values from 1.2 to 1.6 METs were used as metabolic rates, and the activity level of each individual was also considered. To identify the Mean Radiant Temperature ($\overline{T}r$), the empirical formula (1) recommended by (Ref. [9]; pp.129) was adopted. The $\overline{T}r$ is explained in the equation of PMV according to ISO 7730/2005:

$$\overline{T}r = (Tg + 273)^4 + 0,4 \times 10^8 \times |Tg - Ta|^{0,25} \times (Tg - Ta)^{0,25} - 273 \quad (1)$$

2.3.2. *Acoustics*

The equivalent noise level was measured with a handheld sound analyzer *Bruel & Kjaer model 2250 L-200* (precision ± 2 dB) with an "A" ponderation curve and slow response circuit. The measurements were performed at least 1 m away from any surface, such as walls, ceilings, floors and furniture, and at a height equivalent to the average height of the professionals' ear canals measured for eight hours distributed between shifts. The recommendations of NBR 10151 [45] were adopted as the standard of reference.

2.3.3. *Lighting*

The illuminance levels (lux) were read using a lux meter Phywe (precision ± 3%). The collections were performed with the apparatus positioned 1 m from the ground, following the [32] recommendations. The morning shift measurements were performed between 9 a.m. and 10 a.m.; the afternoon shift measurements were performed between 1 p.m. and 2 p.m.; and in the ICUs with natural lighting, measurements were also performed in the early evening, between 6 p.m. and 7 p.m., when natural light was no longer available. Resulting in about 3 h of daily measurement.

2.3.4. *Air quality*

For particle counting (PC), the *Fluke 983* (precision ± 5%, with measuring range above 0,3 μm) instrument was used. The apparatus was calibrated by placing it at previously selected fixed points in the room, positioned at the height at which the task is executed (approximately 1 m from the ground), according to the ISO 14644-1 and NHO 08 recommendations [4]. The concentration of solid particles with a diameter ≤2.5 μm ($PM_{2.5}$) suspended in the air was used as the indicator.

The air quality is affected by a variety of components, such as NO_2, O_3, SO_2, among others, with effects in human health. Therefore, trying to identify separately the effects of certain air components on health can create double counting. Based on this assumption, it was decided to opt for an indicator that measures the concentration of suspended solid particles in the air (PM) because, according to most epidemiological studies, this indicator is more significant compared to other types of indicators when it comes to air compounds [38,50,66].

According to the method used by Refs. [73] and [52]; the irregularly shaped rooms were divided into sectors to facilitate the regularization of the area into rectangles. Measurements were performed individually with a flow rate of 2.83 l per minute, for one minute at each point, with minimum number of collection points allowed by Equation (2) (where "a" is the industry area in m^2), and five measurements at each point, according to the [29] recommendation.

$$\text{No. of points} = \sqrt{\boldsymbol{a}} \quad (2)$$

The $PM_{2.5}$ concentration mass in the environment (μg/m^3) was obtained using the formula proposed by Refs. [60] and [62] (Equation (3)).

$$PM_{2.5} = 0.65 + 4.16 \times 10^{-5} \times (PC) + 1.57 \times 10^{-11} \times (PC)^2 \quad (3)$$

2.3.5. *Perception and satisfaction*

The professionals' perceptions of the environmental comfort variables were captured through a questionnaire (Table 2) that included items for each perception level. The questionnaire was based on previous publications and was administered during the professional's work hours with previous instructions. A single administrator provided instructions to all participants.

2.3.6. *Health and welfare*

The professionals' health and welfare data were collected through a specific questionnaire listing 38 signs and symptoms that the specialized literature recognizes as associated with workplace environmental conditions. This questionnaire also collected information regarding professional experience, number of work hours, rest breaks and lifestyle and was adapted from the MM 040 Hospital - *Indoor Climate in Hospital/Health Care Establishment* questionnaire [12] (Appendix).

2.4. *Data analysis*

The field data, including the location and date of collection, were initially recorded in Microsoft Excel® software, and their central tendency and dispersion measures were analyzed using SPSS software version 20. After these analyses, Bayesian models were

Table 2
Environmental perception questionnaire.

Question	Categories of answers	Source
In terms of temperature sensation, how are you feeling at this moment?	□Comfortable □Slightly uncomfortable □Uncomfortable □Very uncomfortable	[28]
Does the emitted noise bother you?	□ Yes □ No	[12]
How would you rate the air quality in the workplace?	□ Good □ Acceptable □ Bad	[14]
How satisfied are you with the lighting level in your workplace?	□ Satisfied □ Neutral □ Dissatisfied	[13]

constructed to evaluate the occupational risk in relation to the environmental comfort variables in the ICUs.

2.4.1. Construction of probabilistic models

The model structure was based on the construction of Bayesian networks (BN) using “Netica Bayesian Network” software (www.norsys.com). The networks were structured according to the identification of the risk scenario, the estimation of qualitative parameters and calibration, the estimation of quantitative parameters and the validation of the model, according to the following steps:

2.4.1.1. Step I – Risk scenario. The characterization of the risk scenario was based on previous publications, including the studies by Refs. [21–23] and [68,69]; and through the field observations and descriptive data analyses, which allowed us to identify existing dependency relationships among the variables.

2.4.1.2. Step II – Estimation of the BN structure. To identify the graphic structure and estimate the model parameters, a conditional independence test was performed that identified the dependency relationship between each variable from the model. The mutual information (MI) measure was used for this procedure; if MI > 0, the tested *nodes* (representing the random variables) are dependent; otherwise, they are independent.

2.4.1.3. Step III – Structural calibration. The identified graphic structures underwent a calibration process to evaluate the sensitivity and specificity (i.e., the probability that the investigated tests provided positive-real and negative-real, respectively) of the model and, consequently, its ability to predict the occurrence of symptoms. Such indicators allowed us to develop a network structure that was more appropriate for predictions.

2.4.1.4. Step IV – Probabilistic inference. Once the network structure was identified, the inference ability of the model's quantitative parameters is determined using probabilistic and computational calculations. This analysis considers the interaction between theoretical knowledge and the risk scenario as it relates to the study problem presented in the epigraph. Hence, it is possible to arrive to a consistent value for exposure to occupational risk, with the attenuation of possible bias [40].

2.4.1.5. Step V – Validation. The resulting network structure was validated **with indicators that** evaluate diagnostic capability and model prediction. The following indicators were used: area under the Receiver-Operating Characteristic (ROC) curve (Representation generated by the relationship between the Sensibility and the complementary probability of Specificity), positive predictive value (PPV) (probability that the sample expresses the event of interest since the test indicated that such event would happen) and negative predictive value (NPV) (probability that the sample does not express the event of interest since the test showed that this event would not happen), error rates (percentage of the error generated in forecasts), logarithmic loss, quadratic loss and spherical scoring (indicators of the degree of propagation of predicted values between the alternatives of the states). The area under the curve provides an indicator of the network's performance [21,22].

2.4.1.6. Step VI – analyses. Sensitivity analyses were performed to determine which predictor variables had the highest impact on the response variables. This analysis was performed using a graphic representation of the *node* states (the variety of values that the variable can assume) and the construction of the risk scenario, which determined the probability variations given a specific precondition.

3. Results and discussion

3.1. Sample profile

Interviews were conducted with 128 professionals with average age of 35.5 ± 8.2 years and an average body mass index of 26.8 ± 5, corresponding to a healthy body mass. The sample consisted of 80.5% women. In the sample, 53.9% were nurse technicians, 20.3% were physiotherapists, and 18% were nurses.

The average work experience was 7.4 ± 5.9 years, with 46.9% of the sample working more than 45 h per week; 38.3% of individuals working in more than one ICU, and 65.6% of professionals working all three shifts. These percentages were similar to those from studies of European [42] and Asian populations [6], in which the samples were primarily composed of young women with a high number of weekly work hours and a short duration of work experience in the sector.

3.2. Experimental data

The data collected in the field are shown in Table 3. The PMV column provides an estimation of temperature-related comfort. The comfort state ranged from −0.5 to 0.5, with negative values denoting environments with sensations tending toward cold and positive values denoting sensations tending toward hot [31].

Three ICUs presented PMV levels outside the comfort range (1, 2 and 5), with a tendency toward cold. Such levels were influenced by the high humidity values registered, which were within the hygienic ranges stipulated for the sector.

It is noted that the air temperature in ICUs presented itself in a range between 18 and 23 °C, with internal variations prevalently below 2 °C, and humidity with a maximum variation of 6.5%. The highest temperature variations were observed in the sectors of bigger architectural dimensions e higher occupancy rate, which in this case is influenced by the flow of people and the capacity of the HVAC system to offset the space dimensions.

Such variations were consistent with the investigations of [53]; who found ICU temperatures varying at 1.4° and relative humidity at 6.8%. According to the author, the hospital is well controlled as of thermal comfort, where air temperature in the investigated spots varied around 2.1 °C and humidity around 10%. Thus, the temperature and humidity present a distribution within the expected range for each sector investigated.

In all analysis units, the relative humidity showed values well below those required for the sector, this is due especially to inadequate logistics of how the air conditioning is carried out considering that generally, the sectors maintained a single air conditioner for the entire ICU and without maintenance, making the process inefficient to compensate for the characteristic humidity of the sector procedures (e.g. bathing of patients) and also the impact of the external environment, given that the capital of the state of Paraiba, João Pessoa, it is coastal, with hot and humid climate.

In relation to noise, although the ICUs had different characteristics, the acoustic levels of exposure were somewhat similar among the sectors, with field measurements presenting values much higher than those stipulated by NBR 10152:1987 [46].

Likewise, the lighting and air quality levels were maintained at the limits of the normative specifications. According to recommendations, lighting values in these environments should be higher than 300 lx [32]; however, these values were not observed in the investigated ICUs. Therefore, the ICUs were poorly illuminated, which could increase the professionals' attention and effort expenditures and may lead to greater energy use and physical distress [54].

Furthermore, six of the ICUs presented average $PM_{2.5}$ concentrations that were much higher than the 35 μg/m^3 limit established by environmental control organizations [15]. The standard deviation suggests great variability in these environments, which could be related to the interference of the types of tasks executed in the sector [17,34], as the highest concentrations were found for collection points close to where the therapeutic procedures were performed. The super counts were especially present in therapeutic procedures, e.g. the central catheter deployment, the tracheal aspiration and especially the nebulization that affected the $PM_{2.5}$ count even farther away to focus procedure (up to 7.7 m), regressing exponentially after completion.

In this study, the ICUs that had higher average concentration of $PM_{2.5}$ (ICUs 5 and 7) are respectively ventilated by central AC system and have failures in the internal seal, which, according to [34]; strongly influence the air composition of the environment, representing the strongest factors to the internal variability of the air quality.

3.3. Environmental perception

Table 4 shows the professionals' sensations and perceptions of environmental comfort conditions. The observation that 60.1% of the sample indicated temperature discomfort and that in Table 3, the PMV indicates slightly cold sensations, the thermal comfort in this sample tended to be associated with the somewhat low air temperature. This result is frequently present in hot and humid geographical regions [26], such as those of the city in which these hospitals are located.

Among the perception levels, noise stands out as the main source of discomfort, with more than 80% of the participants describing it as unsatisfactory [8]. corroborates these results by noting that 76.09% of intensivists consider the ICU a noisy environment and that 69.57% report feeling bothered by the noise. The technological apparatuses required for ICU interventions could lead to discomfort and stress, as could the combination of sounds produced by the execution of activities, interpersonal conversations and the handling of objects. This noise could result in concentration problems and, as ICU work is essentially intellectual, could affect task performance, starting a chain of events that could lead to various symptomatological complaints.

A more detailed analysis of the factors associated with noise-related discomfort in this sample showed that all of the professionals who felt bothered by the noise worked at ICUs where the average noise level was higher than 62 dBA, indicating that this level was a cut-off point for the acceptability of environmental noise in the studied sample.

3.4. Occupational health

The investigated symptomatological complaints were grouped according to their psychological and physical nature, as shown in Table 5. Such occupational symptoms occurred at an average rate of 9.1 ± 7.3 in the sample, and the following symptoms occurred most frequently: annoyance, mood changes, anxiety and stress in the category of psychological symptoms; and headache, sore throat, muscle pain, sneezing, physical fatigue and muscle tension in the category of physical symptoms.

Along with the symptomatological occurrence, we investigated how these symptoms presented in the sample. We observed that 53.9% of the professionals reported experiencing the beginning or worsening of the symptoms during work hours, while 57.03% noted that the symptoms decrease or disappear when they conclude their work, especially upon exiting the workplace environment.

3.5. Bayesian networks

3.5.1. Risk scenario

The *nodes* of the network were stratified in mutually exclusive states according to the characterization of the study environment in terms of the descriptive experimental, perceptive and symptomatological data. The states of the “PMV” and “Noise” *nodes* considered the differences in the participants' self-reported comfort

Table 3
Trial data, presented as averages and standard deviations.

ICU	PMV	Temperature (°C)	Humidity (%)	Noise (dB[A])	Illumination (Lx)	$PM_{2,5}$ (μg/m^3)
1	−1.25 ± 1.06	19.3 ± 0.7	84.8 ± 1.3	58.2 ± 2.9	83.6	19.2 ± 7.2
2	−1.01 ± 0.2	22.8 ± 0.5	78.9 ± 1.9	58.3 ± 6.1	58	17.2 ± 9.1
3	−0.48 ± 0.3	21.1 ± 1.7	77.6 ± 3.7	65.2 ± 1.8	51.03	22.7 ± 9
4	−0.29 ± 0.16	20.3 ± 0.4	82.2 ± 1.2	65.6 ± 4.2	148.9	48.3 ± 30.8
5	−0.85 ± 0.37	20 ± 1.9	82.4 ± 6.5	62.5 ± 2.6	172	132.3 ± 38.1
6	−0.09 ± 0.6	22 ± 1.1	81.1 ± 3.3	62.2 ± 3.4	177.6	59.4 ± 69.9
7	−0.14 ± 0.19	22.3 ± 0.6	75.4 ± 1.8	62.9 ± 3.3	60.1	156.9 ± 77.1
8	0.01 ± 0.2	22.9 ± 0.9	74.9 ± 2.5	62.4 ± 3.2	134.4	72.7 ± 35
9	−0.15 ± 0.23	21.8 ± 1.1	74.1 ± 2.7	61.4 ± 3.4	77.5	71.3 ± 42

Table 4
Environmental perception.

Sensation category	Answer category			
Temperature perception	Comfortable 60.1%	Slightly uncomfortable 33.6%	Uncomfortable 5.5%	Very uncomfortable 0.8%
Air quality perception	Good 14.8%	Acceptable 56.2%	Bad 28.9%	
Light perception	Satisfactory 47.6%	Neutral 37.5%	Unsatisfactory 14.8%	
Noise perception	Uncomfortable 82.3%	Not uncomfortable 17.7%		

levels, i.e., in the categorization of the states, the sample's perceptions were adopted as the reference. However, the structure of the state of the "Illumination" and "Air quality" *nodes* took into account the [3,15,32,71] guidelines, respectively. The *nodes* associated with the professionals' perceptions followed the categorization procedure used in the questionnaire.

Regarding the symptomatological complaints, the individuals were distributed into two groups according to the occurrence of the most frequent symptoms. These groups represented frequencies of 50% or higher. Hence, among the psychological symptoms, the groups comprised the individuals who had 4 or more of the most frequent symptoms (≥4 symptoms). Also, in terms of the physical symptoms, groups were formed with the individuals who had 6 or more of the most frequent symptoms (≥6 symptoms) presented in Table 5.

3.5.2. Estimation and calibration of the network structure

Table 6 presents the mutual information data on which the network structure was based. It can be observed that the *nodes* related to the illumination, noise, PMV and air quality variables presented the most remarkable relationships of mutual dependency (values higher than zero), indicating possible connections.

The resulting network (Fig. 1) was calibrated to test the sensitivity and specificity of the predictions. The calibration considered the occurrence of ≥4 psychological symptoms and ≥6 physical symptoms as interesting events.

The model was representative of the symptomatological occurrences, especially for physical symptoms, because 100% of times that the BN indicated the occurrence of ≥6 physical symptoms, this occurrence level was actually present in the sample, while in 95.3% of cases, when the network diagnosed the non-occurrence of such symptoms, they were not present in the sample. As for the psychological symptoms, in 85.7% of the time in which the BN indicated the occurrence of ≥4 symptoms, that level was indeed present in the sample, and in 89.9% of cases in which the BN indicated that such symptoms would not occur, they were not present.

Hence, it can be said that the network structure resulting from the calibration provides a greater than 85% probability of obtaining the correct result regarding the occurrence or non-occurrence of the given set of symptoms.

In the proposed network model (Fig. 1), it can be seen that the environmental occupational factors associated with symptomatic occurrence present itself in an interconnected way, in a tangle where mutual associations determine the outcomes. It appears that some factors are direct predictors for the symptomatic occurrence, such as "PMV", that has direct arrows to the nodes related to the symptoms, however factors such as "lighting" have influence mediated by the perception that the professional has of this subject. This view allows the identification that environmental parameters can have direct impacts on health issues and well being of the sample investigated, but the way these parameters are present in the environment, the associations, the perceptual issues define the real systemic conception of the problem.

3.5.3. Validation of the network

The validation indicators for each category of symptomatic complaints are shown in Table 7. These data show that for both variables of interest, the indicators proved to be satisfactory in their predictions. The PPV indicates the probability of the sample manifesting the set of symptoms of interest when the BN predicted that it would, with a probability greater than 80%. The NPV indicates the probability of the sample not manifesting the set of symptoms of interest when the BN predicted that it would not, resulting in a probability higher than 90%. In the case of the NPV for the occurrence of physical symptoms (Table 7), in 100% of cases in which the BN predicted that the symptoms would not occur, they did not. In other words, the BN was capable of predicting the occurrence of the set of symptoms of interest and the non-occurrence of the set of symptoms, and its predictive ability was strongest for cases of non-occurrence.

The other indicators corroborated with the validation of the model and indicated that the BN had a stronger ability to predict

Table 5
Occurrence of symptomatological complaints.

Psychological symptoms					
Annoyance	73.4%	Lack of motivation	42.2%	Lethargy	8.6%
Mood changes	60.2%	Concentration problems	32.8%	Nervousness	29.7%
Memory changes	35.2%	Stress	62.5%	Loss of appetite	11.7%
Anxiety	59.3%	Insomnia	35.9%	Anger	37.5%
Depression	8.6%	Irritability	48.4%		
Physical symptoms					
Tinnitus	30.5%	Visual fatigue	30.5%	Rhinitis	32.8%
Burning eyes[a]	37.5%	Pharyngitis	32.8%	Dry skin	29.7%
Headache	64.8%	Dry throat	32.8%	Tachycardia	21.1%
Nasal congestion	47.6%	Hypertension	20.3%	Muscle tension	53.9%
Sore throat	55.5%	Skin rash	16.4%	Dizziness	20.3%
Muscle pain	66.4%	Eye tearing	16.4%	Cough	31.3%
Sneezing	50%	Eye redness	17.9%	Palpitation	27.3%
Physical fatigue	60.9%	Mucosal irritation	17.2%	Hearing loss	8.6%

[a] Irritation in the eyes or discomfort in the eyes.

Table 6
Mutual information.

	Physical symptoms	Psychological symptoms	PMV	Temperature perception	Noise	Noise perception	Lighting	Light perception	Air quality	Air quality perception
Physical symptoms		0.042	0.002	0.039	0.002	0.004	0.015	0.048	0.011	0.043
Psychological symptoms	0.042		0.016	0.020	0.004	0.009	0.015	0.094	0.006	0.051
PMV	0.002	0.016		0.063	0.114	0.049	0.041	0.094	0.109	0.026
Temperature perception	0.039	0.020	0.063		0.036	0.030	0.019	0.097	0.066	0.133
Noise	0.002	0.004	0.114	0.036		0.056	0.233	0.007	0.094	0.007
Noise perception	0.004	0.009	0.049	0.030	0.056		0.009	0.034	0.031	0.030
Lighting	0.015	0.015	0.041	0.019	0.233	0.009		0.023	0.153	0.010
Light perception	0.048	0.017	0.094	0.097	0.007	0.034	0.023		0.051	0.099
Air quality	0.011	0.006	0.109	0.066	0.094	0.031	0.153	0.051		0.029
Air quality perception	0.043	0.051	0.026	0.133	0.007	0.030	0.010	0.099	0.029	

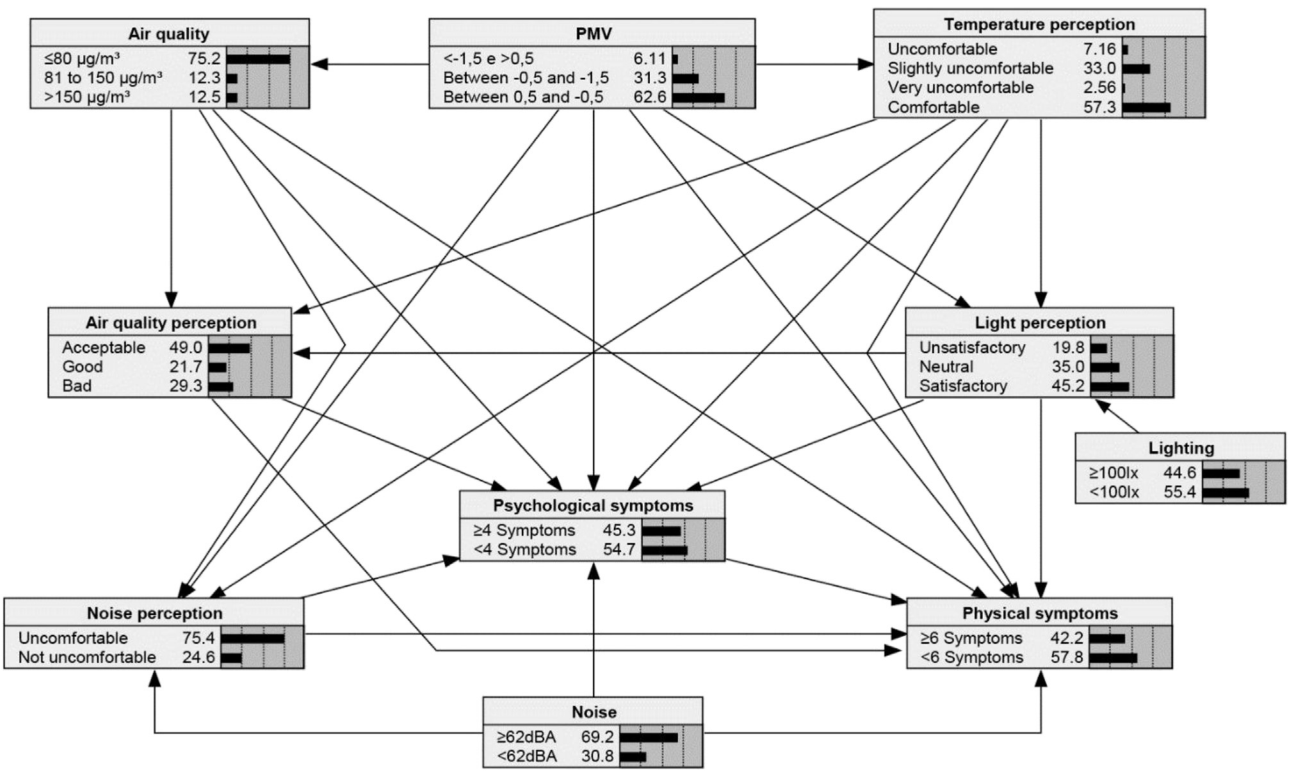

Fig. 1. Bayesian networks model.

the set of physical symptoms, as the error rate, logarithmic loss and quadratic loss were maintained at values closer to 0 and, concomitantly, the area under the ROC curve and spherical scoring maintained values closer to 1.

3.5.4. *Sensitivity analyses*

Analysing the simple probabilities of symptomatological complaints in contrast with the conditional probabilities, given the interactions of the experimental environmental and perceptive variables, it can be observed that the interactions among the environmental variables could change the probability of having ≥6 physical symptoms from 17.7% to 42.2%, an increase of 24.5%, and could change the probability of having ≥4 psychological symptoms from 38.4% to 45.3%, an increase of 6.9%.

Such values result of the interactions of all of the BN variables, and they consider the environmental context in which the data were collected and the perceptions of the professionals in this environment. However, such values do not reveal the isolated potential of each variable and how it could affect the probabilities of symptomatological occurrences.

For this purpose, an individual sensitivity analysis was performed with the graphical manipulation of the *nodes* to identify the power of the impact of each predictor and mediator variable on the result variables and to possibly determine the increases in the positive (increase of basal probability) or negative (reduction of basal probability) probability that the set of symptoms under consideration would occur (Table 8).

This analysis paid particular attention to temperature characteristics, as they factors that had the greatest influence on the risk of both physical and psychological occupational symptomatological complaints. The change from a predicted comfort state of “between −0.5 and 0.5” to a discomfort state of “<-1.5 and >0.5” increased the risk of having ≥6 physical symptoms from 40.7% to 48.7% (an increase of 8%) and increased the risk of having ≥4

Table 7
Indicators of model validation.

	Positive predictive value	Negative predictive value	Error rate	Area under ROC area	Logarithmic loss	Quadratic loss	Spherical scoring
Physical symptoms	0.8113	1	3.901%	0.9914	0.3578	0.1903	0.9081
Psychological symptoms	0.8404	0.9093	11.72%	0.9525	0.383	0.2182	0.8871

psychological symptoms from 46.1% to 49.6% (an increase of 3.5%). Similarly, on a perceptive level, the results were equivalent; however, there were greater increases in probability. In this case, the change from a comfort state could generate an 11.4% increase in the probability of having an increased number of physical symptoms and a 9.6% increase in the probability of having an increased number of psychological symptoms.

A comfortable temperature could be a priority attribute in relation to the other variables because temperature had the greatest weight in the evaluation of overall environmental comfort [19,36] and could determine professionals' tolerance of other environmental components [25].

However, the effects of temperature were not similar for both symptom categories. The comfort zone of the “PMV” *node* reduced the probability of the occurrence of physical symptoms; however, it did not have the same effect for the psychological symptoms. In other words, the predictive ranges of PMV could have different effects on the symptomatological occurrence, because while comfortable levels reduced the probability that physical symptoms would occur, only the predictions of slightly cold temperatures represented by states “between −1.5 and −0.5” could reduce the probability of psychological symptoms.

These results are consistent with those of previous publications. For instance [21], showed that temperature was the most important parameter of occupational risk, contributing to a 13.6% increase in the occurrence of physical symptoms, and [42] indicated that temperature, light and acoustic discomfort levels increased the probability of developing musculoskeletal disorders in the upper extremities and lower back by 10–58%.

Lighting perception was the parameter with the second greatest influence on symptomatological occurrence. On a perceptual level, the change from a state of satisfaction with the lighting to dissatisfaction increased the risk of physical symptoms from 37.5% to 49.3% (an increase of 11.8%) and the risk of psychological symptoms from 40.2% to 49.2% (an increase of 9%).

The *nodes* associated with noise and noise perception had divergent results. In the ICUs where the noise measurements were lower than 62 dBA, the professionals had a reduced risk of developing the set of physical and psychological symptoms under consideration, and the reduction was similar for both symptom categories. However, noise perception did not show similar results. The sensitivity analysis of the “noise perception” *node* showed a peculiar result. In this case, the state of discomfort reduced the risk of developing symptomatological complaints by 1.7% compared with the “not uncomfortable” *node,* which increased the risk by 4.9%.

This fact could be explained from the adaptive perspective: when the body is exposed for long periods to noise, it tends to adapt to the environment as a defense and self-protective mechanism, so that noise that would be uncomfortable for an new occupant would be considered not uncomfortable by others who have operated in that environment for longer [56]. Within this context [59], revealed that 97% of ICU professionals consider the noise of the unit moderate to intense, but only 50.7% felt bothered by it. Also, according to [58]; the source of noise is a factor that can direct the professional's perception, as the discomfort caused by equipment noises can result in uncomfortable perceptive sensations even when the actual exposure level is not particularly high.

Regarding the air quality conditions, the only situation that reduced the risk of symptomatological complaints was exposure to $PM_{2.5}$ concentrations lower than 80 $\mu g/m^3$, as stipulated by the World Health Organization [71], the Environmental Protection

Table 8
Sensitivity analysis.

		Physical symptoms ≥6 symptoms (%)	I[a]	Psychological symptoms ≥4 symptoms (%)	I[a]
Initial stage		42.2		45.3	
PM	Between 0.5 and −0.5	40.7	−1.5	46.1	0.8
	Between −0.5 and −1.5	43.8	1.6	43	−2.3
	<-1.5 and >0.5	48.7	6.5	49.6	4.5
Temperature perception	Comfortable	38.8	−3.4	42.7	−2.6
	Slightly uncomfortable	46.1	3.9	47.9	2.6
	Uncomfortable	47.9	5.7	52.3	7
	Very uncomfortable	50.2	8	50.3	5
Noise	<62 dBA	45.6	−1.6	48	−1.2
	≥62 dBA	40.6	3.4	44.1	2.7
Noise perception	Uncomfortable	40.5	−1.7	44.9	−0.4
	Not uncomfortable	47.1	4.9	46.6	1.3
Lighting	≥100 lx	41.7	−0.5	45	−0.3
	<100 lx	42.5	0.3	45.6	0.3
Light perception	Satisfactory	37.5	−4.7	40.2	−5.1
	Neutral	44.1	1.9	49.7	4.4
	Unsatisfactory	49.3	7.1	49.2	3.9
Air quality	≥80 $\mu g/m^3$	41.1	−1.1	41.1	−4.2
	81 to 150 $\mu g/m^3$	45.6	3.4	47.9	2.6
	>150 $\mu g/m^3$	45.3	3.1	50.3	5
Air quality perception	Acceptable	38.6	−3.5	42.2	−3.1
	Good	44.1	1.9	43.4	−1.9
	Bad	46.7	4.5	52	6.7

[a] I = Increase in probability.

Agency [15] and ANVISA resolution no. 09 [3]. The air quality in the hospital environment is especially relevant to safety and health studies of the exposed population because high suspended particulate matter concentrations in hospital environments increase the risk of airborne infectious transmission by approximately 40% for an exposure of 40 h per week [33]. Given that in most cases, the professionals included in this study are exposed for more than 40 h per week and that ICUs are particularly susceptible to the presence of infectious diseases, the risk of contracting infectious diseases could increase even further.

Among the other results, the greatest risk increases were generated by the effect of the environmental comfort attributes (with the exception of air quality and perceived air quality) on the occurrence of the measured physical symptoms; for such symptoms, the professionals' perceptions of and satisfaction with the environment were the indicators with the greatest influence. This occurred because the subjective variables were more highly correlated with the overall experience than the variables that could be measured quantitatively [18]. Hence, the subjective data helps to understand and identify potential problems in the environment that could be improved using the data collected in the field [10].

The sample profile could have biased the professionals' perceptions of the environment, as individual perceptions of the environment are strongly influenced by gender. In the present study, women under 50 years of age tended to judge the environment more severely than the men did, having a 12% greater probability of feeling dissatisfied with the temperature, a 69% greater probability of being dissatisfied with the air quality and a 29% greater probability of feeling dissatisfied with the lighting [37]. Therefore, women had more complaints in relation to the environment and, concomitantly, could be more prone to developing related symptoms.

Moreover, the sensitivity analyses indicated that the increases in risk generated from variations of the *node* states in the BN are nonlinear and asymmetrical and could therefore generate different risk amplitudes for the different states; i.e., the optimal state for a specific variable does not necessarily lead to a reduction in risk compared with the worst state.

The sensitivity analysis of the mutual influences of the result *nodes* is presented in Table 9. The individuals who had ≥6 physical symptoms had a 4.6% increased risk of the concomitant occurrence of ≥4 psychological symptoms. Inversely, the individuals who presented ≥4 psychological symptoms had a 2.4% increase in for the concomitant occurrence of ≥6 physical symptoms.

To assess whether the variables associated with temperature comfort have a greater probabilistic weight in the occurrence of symptomatological complaints, two risk scenarios were created. These scenarios used the temperature comfort and discomfort states to verify how the other variables behave by observing the synergy between the environmental components and their effects on the professionals' health conditions and welfare. The starting point was the characterization of the environmental temperature, and the risk resulting from the interactions between the indoor environmental variables considered the different states that could be assumed by the other variables.

3.5.5. Scenario 1: an environment with a comfortable temperature

In this first scenario, the environment has a PMV-estimated temperature within the neutral range, and the professionals' self-reported temperature perception is “comfortable”. From this moment, the “initial stage” is changed because there is an established pre-condition.

Table 10 Presents the results for the interactions between temperature and the other requirements for environmental comfort. In contrast with the results shown in Table 8, the effects of the exposure to the other variables are strengthened.

In relation to the variations in the probability of occurring physical symptoms, the “Noise”, “Air quality” and “Atmospheric perception” *nodes* stand out as the main factors that increase the risk in this scenario, changing from the increase of 3.4%–9% in a situation of “≥62 dBA”; from 3.1% to 6.7% in a situation of “>150 μg/m^3”; and from 4.5% to 8.8% in a situation of “Bad” atmospheric perception, respectively.

In the case of the psychological symptoms, the main factors that increase the risk were, again, the *nodes* “Noise”, “Air quality” and this time “Lighting perception”, changing from the increase of 2.7%–7.5% in a situation of “≥62 dBA”; from 5% to 10.8% in a situation of “>150 μg/m^3”; and from 3.9% to 10.2% in a situation of “Dissatisfaction, respectively, in regards to the light perception.

In some cases, the new probability increases doubled or almost tripled in a scenario of thermal comfort. This is because by positioning in the best situation possible, the increase of the effects was verified on the other variables as they became evident.

Hence, the thermal neutrality range in which the professional is found could influence his or her judgment on the other variables and could also determine their tolerance zones [49], as well as how they affect the probability of occurring symptomatological complaints from professionals.

3.5.6. Scenario 2: an environment with an uncomfortable temperature

Table 11 presents the risk in the new scenario, where the temperature of the environment causes discomfort for the occupant. Most of the environmental attributes tend to present a reduction in their possible predictive effects. This is caused by the predominance of temperature in the perceptive priority, which tends to position the environment's temperature as the main quality that determines an individual's comfort.

A comparison of Tables 8 and 10 indicates that the environmental variables of noise, lighting and air quality in an environment with an uncomfortable temperature had a reduced impact on the symptomatological incidence.

Hence, in an environment with a comfortable temperature, other environmental aspects have an amplified impact on health conditions, while in an uncomfortable environment, the discomfort caused by the temperature is the main driver of health complaints.

Table 9
Mutual sensitivity analysis.

		Physical symptoms ≥6 symptoms (%)	I[a]	Psychological symptoms ≥4 symptoms (%)	I[a]
Initial stage		42.2		45.3	
Physical symptoms	≥6 symptoms			49.9	4.6
	<6 symptoms			42	−3.3
Psychological symptoms	≥4 symptoms	44.6	2.4		
	<4 symptoms	38.6	−3.6		

[a] I = Increase in probability.

Table 10
Risk scenario in an environment with a comfortable temperature.

		Physical symptoms	I[a]	Psychological symptoms	I[a]
		≥6 symptoms (%)		≥4 symptoms (%)	
Initial stage		37.4		43.8	
Noise	<62 dBA	33.4	−4	41.3	−2.5
	≥62 dBA	46.4	9	49.3	7.5
Noise perception	Uncomfortable	35.3	−2.1	43.7	−0.1
	Not uncomfortable	45.3	7.9	43.8	0
Lighting	≥100 lx	36	−1.4	42.9	−0.9
	<100 lx	38.5	1.1	44.4	0.6
Light perception	Satisfactory	32.4	−5	41.2	−2.6
	Neutral	40.1	2.7	42.6	−1.2
	Unsatisfactory	47.9	10.5	54	10.2
Air quality	≥80 μg/m^3	35.1	−2.3	40.9	−2.9
	81 to 150 μg/m^3	50		50	
	>150 μg/m^3	44.1	6.7	54.6	10.8
Air quality perception	Acceptable	33.4	−4	44	0.2
	Good	39.1	1.7	38.3	−5.5
	Bad	46.2	8.8	49.6	6.8

[a] I = Increase in probability.

Table 11
Risk scenario in an environment with an uncomfortable temperature.

		Physical symptoms	I[a]	Psychological symptoms	I[a]
		≥6 symptoms (%)		≥4 symptoms (%)	
Initial stage		49.1		51.4	
Noise	<62 dBA	47	−2.1	54.5	3.1
	≥62 dBA	50		50	
Noise perception	Uncomfortable	48.3	−2.1	52.5	−0.1
	Not uncomfortable	50		50	
Lighting	≥100 lx	49.4	0.3	51	−0.4
	<100 lx	48.8	−0.3	51.7	0.3
Light perception	Satisfactory	50		50	
	Neutral	48.1	−1	52.9	1.5
	Unsatisfactory	50		50	
Air quality	≥80 μg/m^3	48.8	−0.3	51.7	0.3
	81 to 150 μg/m^3	50		50	
	>150 μg/m^3	50		50	
Air quality perception	Acceptable	49.3	0.2	51.1	−0.3
	Good	50		50	
	Bad	48.6	−0.5	52.2	0.8

[a] I = Increase in probability.

This finding shows that the other environmental attributes have contribute less to the risk of developing symptoms because temperature characteristics seem to dominate the perceptive priority.

Thus, it is evident that the synergy of the indoor environmental quality variables plays a very interesting role in determining how and to what extent such variables affect the health conditions of the exposed population and could therefore shed some light on conflict points and possible areas for adjustment.

4. Conclusions

The present study aimed to investigate the risk of symptomatological complaints related to exposure to the indoor environmental quality variables in ICUs. The construction of the BN model allowed the estimation of the prediction force of each studied variable and provided an understanding of the effects of the interaction among the environmental variables on the occurrence of the physical and psychological symptoms that represented experimental and subjective variables.

Regarding the isolated risk estimations, the temperature perceptions of the participating ICU professionals were associated with a risk of approximately 8% for the occurrence of the set of symptoms considered in the analysis (annoyance, mood changes, anxiety, stress, headache, sore throat, muscle pain, physical fatigue and muscle tension). This percentage is very similar to that reported in the PMV theoretical model of [31]. The lighting variable had the second-greatest impact; it contributed to 7.1% of the risk of symptomatological complaints. The air quality variable generated a risk increase of 6.7%. The acoustic aspects were associated with a risk increase of approximately 3.4%.

The interaction of environmental attributes in a risk scenario can produce combined effects, indicating that the temperature aspects of an environment can affect other environmental variables to have a greater impact on the health of the professionals as a result of perceptive priority. Hence, in a thermally comfortable environment, the increase in the probability of symptomatological complaints related to the other environmental comfort attributes ranged from 0.6% to 10.8%. However, taking into account only the variables illumination, noise and quality, the increments remained between 0.2% and 3.1%, showing that the thermal variable related to other attributes of comfort is the main source of risk in ICUs.

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Appendix. Symptomatological questionnaire.

Profession: ☐ Doctor ☐ Nurse ☐ Physiotherapist ☐ Nurse technician

Age:___________________ Height:___________________ Weight:____________________

Gender: ☐ Female ☐ Male

1) What is your weekly work time:

☐ Up to 20 h ☐ Up to 30 h

☐ Between 30 and 45 h ☐ Between 45 and 60 h

☐ More than 60 h

2) Do you work in more than one ICU? ☐ Yes ☐ No

3) What shifts do you work?

☐ Only in the morning ☐ Only in the afternoon

☐ Only in the morning and afternoon ☐ Morning, afternoon and night

☐ Only at night

4) Do you consume alcohol? ☐ Yes ☐ No

5) Do you smoke? ☐ Yes ☐ No

6) Do you exercise regularly? ☐ Yes ☐ No

7) Do you have any pre-existing pathological disorders? ☐ No ☐ Yes

Check the sign and symptoms below that you experienced in the last 3 months and that, in your opinion, are related to the environmental characteristics of your workplace.

Annoyance	☐	Insomnia	☐	Cough	☐
Tinnitus	☐	Irritability	☐	Eye redness	☐
Mood changes	☐	Skin rash	☐	Mucosal irritation	☐
Memory changes	☐	Watery eyes	☐	Hypertension	☐
Anxiety	☐	Lethargy	☐	Physical fatigue	☐
Burning eyes	☐	Nervousness	☐	Visual fatigue	☐
Headache	☐	Palpitation	☐	Pharyngitis	☐
Nasal congestion	☐	Loss of appetite	☐	Dry throat	☐
Depression	☐	Hearing loss	☐	Tachycardia	☐
Lack of motivation	☐	Anger	☐	Muscle tension	☐
Concentration problems	☐	Rhinitis	☐	Dizziness	☐
Sore throat	☐	Dry skin	☐	Muscle pain	☐
Sneezing	☐	Stress	☐		

When do your symptoms first appear?

☐ At the beginning or during the shift ☐ During work activities ☐ Other

Do your symptoms decrease or disappear when you leave your workplace?

☐ Yes ☐ No

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