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The Need for a Paradigm Shift toward an Occupant-Centered Environmental Control Model

Paulina Wegertseder-Martínez

Departamento de Diseño y Teoría de la Arquitectura, Universidad del Bío-Bío, Avda. Collao 1202, Concepción 4081112, Chile; pwegertseder@ubiobio.cl

Abstract: Office-based environmental control systems are centralized and designed to control entire spaces, ignoring use dynamics and requirements, and despite being regulated by standardized comfort models, they fail to satisfy real occupants, mainly due to their varied individual characteristics. This research is field-based with a quantitative approach and correlational design. Its objective is to empirically demonstrate that open-plan design, where different users share the same space and generalized environmental conditions, lacks a holistic view of IEQ criteria and the integration of other factors that affect health and well-being. Four buildings are chosen in different Chilean cities, measuring temperatures and CO_2 levels at different desks, and applying a survey, which was designed as part of the research to analyze the estimation of relationships between variables and to reveal the factors that cause differences among occupants. The results show that people's satisfaction is multivariable and depends on other factors that positively or negatively stimulate their sensations and perceptions, such as, for example, the option to personally control their environmental conditions. Likewise, it is evident that to achieve comfort, health is being affected while in the building.

Keywords: open-plan offices; comfort model; occupant satisfaction; post-occupancy evaluation (POE)

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1. Introduction

Nowadays, it is clear that no country, nor the people who live there, are unaware of global issues such as climate change, and the spread and transmission of epidemics (for example, the SARS-CoV-2 coronavirus).

Climate change (CC) has led building design to look at minimizing environmental impacts, but without sacrificing the living conditions of occupants. In developing countries, buildings have failed to meet basic energy demands, unlike in developed countries, where energy use has met the demand but is wasteful and inefficient. This is especially visible in non-residential buildings, where workers do not "pay the bill", and show little awareness of habits to mitigate CC. It is the people who consume energy, not the buildings [1].

On the other hand, the latest epidemic has left in its wake some important lessons about how future buildings should be built, operated, and maintained. These should provide healthy environments, and despite being shared spaces (offices, hospitals, schools, etc.), infection should be avoided among the people there.

In the case of offices, companies such as Google, Apple, and Meta have made progress on new designs that break with convention and that better manage the use of space, improving not just creativity, but also worker satisfaction and mental health [2]. The design of these spaces is flexible and adapted considering different individual needs. However, these are conceived under formal spatial terms and do not necessarily consider factors from the perspective of indoor environment quality. Although they provide "neutral" environments and the perception of comfort for most people, the Indoor Environmental Quality (IEQ) parameters in offices ignore the diversity of inter (between one individual and another) and intra-individual (for the same person, but, at different times) requirements and expectations generated by multiple factors, such as age, sociocultural levels, and health, among others. Under the conventional model, some occupants will feel neither satisfied nor comfortable in the same comfortable environment [3,4].

In addition, in this type of building, the focus has mostly been on thermal comfort, understood as an essential goal to improve user satisfaction, health, and productivity [5,6]. To meet this goal, whether in developed countries or not, thermal comfort models are used that deal with the needs of a general population based on a neutral acceptance under static conditions (80% satisfied in the cases of Predictive Mean Vote-PMV, and a temperature range that considers the satisfaction of healthy adults for ASHRAE). That is to say, the prediction works for just one group of people and not at an individual level, generating discrepancies in satisfaction results in the same premises [7–10]. Aside from this, local temperatures experienced by an occupant and their individual thermal preferences vary greatly in different parts of the building, within the same thermal zone, and even under the same conditions at different times [3].

On the other hand, being satisfied with the indoor thermal performance does not implicitly affect the general satisfaction of the workspace. Some research made in offices with "green" certifications, where IEQ factors fit the highest building standards [11,12], has shown that the factors which affect satisfaction most are privacy, acoustics, and proxemics, and not just what is required to improve IEQ. This also contradicts the architectural premise which indicates that open-plan design improves communication between colleagues and generally improves working environment satisfaction [13]. This assertion is reduced solely to the analysis of a spatial argument, ignoring the impact of people's conceptual relationships [14] and the preferences they have regarding the use of the space.

While personal offices have high levels of thermal control and thus higher satisfaction levels, open-plan offices save energy in exchange for limited environmental control, but at a cost, as they generate health problems by having poor or non-existent indoor environment control. Therefore, making a comparison between energy benefits and satisfaction is important. In Norway, for example, since the regulation of a mandatory provision of thermal comfort control for office users came into force, there has been a 35% improvement in satisfaction and a 20% improvement in comfort, but also an increase in energy consumption [15].

People value a workplace that provides a balance between open spaces to work as a team and encourages communication, with individual spaces to focus on work. They also value flexibility and non-static spaces to meet varying needs, as well as an option to customize or personalize, which allows the user to have an identity, positively affecting their psychological well-being [2,16].

The comfort models that govern the design and current management of buildings have two main issues if it is considered that the buildings of the future must adapt to new challenges in terms of health and energy performance. First, they do not implicitly include physical, mental, and social health as a dimension to evaluate, nor do they consider well-being. In fact, they appear to assume that comfort, whose definition for the built environment has not been accurately defined, in some way ensures well-being. Comfort, however, responds to immediate requirements that can positively or negatively affect the occupant's well-being and health. Second, it is seen that research on IEQ focuses on thermal comfort, with fledgling studies on indoor air quality, although fundamental stimuli to reach optimal indoor environmental quality are not considered.

Thus, this research presents objective and subjective results that question current comfort models and support the basis to change their paradigm (static and designed for one group of people) to dynamic models, focused on the occupant as an individual with specific characteristics and requirements. These results do not focus solely on comfort, but rather include well-being and health as an essential goal that considers asymmetry and transitoriness as somewhat more than a simple disturbance of neutrality.

It is for this reason that this proposal includes not only thermal comfort and air quality, but also looks to explore those acoustic, visual, ergonomic, and spatial parameters that could have implications on the occupant's health and satisfaction, using a survey and experimental measurements that allow providing early guidelines for designs that consider dynamic occupant-centered requirements and stimuli.

This research looks to demonstrate that there are superpositions and important conceptual separations between the positive and negative stimuli that affect individual comfort, well-being, and health in collectively used office building spaces.

As a result, the methodology of this research allows researchers to identify the factors that affect the quality of the working environment in shared offices and provides valuable information to improve worker efficiency and productivity under these conditions, especially job satisfaction. This approach can also contribute toward creating guidelines and policies that promote a healthy and efficient working environment, which could positively affect worker well-being and performance, and ultimately, the success of companies.

2. Materials and Methods

The methodology is based on a field study whose results and characterizations are analyzed correlationally. The variables considered are qualitative and quantitative and are associated with environmental conditions (temperature and air quality), demographic characteristics, and occupant perception regarding IEQ comfort, health, well-being, and productivity. The field study covers two one-week periods, one in summer and one in winter.

Four office buildings in real conditions are chosen in different Chilean cities, with obvious differences in their climatic characteristics (temperature, RH, solar radiation, etc.). The selection criterion is that the buildings have open plans as shared spaces for workers, but with personal desks, a wide heterogeneity of people in terms of gender, age, health, etc., and that the building has been designed for exclusive office use.

A total of 60 Netatmo smart home weather stations (Figure 1) were installed on desks in the chosen study areas to collect the environmental conditions. Other more detailed data were collected from the occupants, namely, distance from a window, their position vis-à-vis the window, their orientation, the type of desk grouping (attached or isolated), the desk size, and their proximity to the air-conditioning system.

Figure 1. Home Weather Station Netatmo Interior, Exterior y App.

The survey is also designed to check the differences in the spaces and get to know user perception, which in addition to asking about IEQ indicators, includes health and well-being aspects. This is then applied to all the building's occupants and not just to those sitting at desks where the weather stations are installed.

2.1. Survey Process

Since 2014, the WELL Building Standard® certification system has included surveys with a more comprehensive vision which are applied one year after the initial certification. However, they are paid surveys and there are discrepancies among the 10 approved surveys [17] which have varying criteria, with some more robust than others. Therefore, the proposal here is to develop a holistic survey to estimate relationships between variables and reveal factors that cause differences among occupants regarding satisfaction, health, and other aspects. The tool must also be able to be applied in buildings with and without air-conditioning, and that do not have exclusive energy efficiency and/or "green certifications".

To define the survey's scope and parameters, a state-of-the-art review was made on three aspects: scientific articles on comfort, well-being, or health surveys in the built environment, surveys validated and applied by WELL certification systems, and studies that determine which office buildings strategies cause people physical, mental, and/or social discomfort.

Four main domains are identified (Table 1), which coincides with the content of other surveys [18–21], but unlike these, this version is more salient for the South American social and economic context and does not only address "tangible" aspects of the building design, but also those related to occupant well-being. Personal and office-type characteristics are gathered, which include categorical, ordinal, and scalar data, to analyze two or more variables that could be grouped, with correlation. One of the hypotheses used to prepare the survey is that people who mention having control over environmental changes, or who have private offices, tend to feel more satisfied in terms of "comfort in the workplace". Another hypothesis for health, well-being, and productivity is that a greater impact on a better or worse result in these three issues is based on the use of the space; that is to say, if many people share an office, if they have no opportunity to personalize the space, if the furnishings and especially the furniture cannot be adjusted, if the external views are not of nature, and/or if they have limited space on their desk, etc., the user is negatively affected.

The comfort domain is evaluated under two aspects: perception and satisfaction, understanding that perception is a selective translation of stimulation by the brain, while satisfaction is related to a state of pleasure that may or may not be influenced by the perception of the comfort of one or more factors [22]. Thus, it is understood that some short-lasting actions an occupant performs are not necessarily pleasant, but seek to achieve "right here, right now" comfort. Meanwhile, satisfaction is more complex to link to bounded variables, such as an action performed. Comfort refers to the physical condition of the occupant, while satisfaction is influenced not only by the physical, but also by the physiological, the mental, and expectations [23] which, depending on our experiences, culture, memories, etc. are different. That is why it cannot be concluded that it is because of the good thermal performance of the indoor space that the user says they are satisfied. The variables involved in their answer are others that are not being quantified [24].

Key questions and some previously unvalidated ones are chosen to be reviewed by 10 experts from Costa Rica, Denmark, Spain, Argentina, the USA, and Belgium who had lived in Chile for at least 6 months to get to know the applicability in this climate and socio-economic context. Using this review, adjustments were made to the survey which included eliminating some response options and a few questions in their entirety, along with reorganizing some multiple-choice options. Another relevant change was differentiating between cold and warm seasons for thermal comfort questions.

Once the survey had been adjusted, a pilot test was run in a real laboratory context in an office building with different workspace typologies. This had a Mediterranean-Oceanic climate, where temperatures are normally below the acceptable comfort range; hence, heating demand predominates. This exercise allowed suitably defining the main lines of evaluation for the surveys, getting to know the relationships between domains, and understanding the influence and dependence between the variables that were asked about.

Table 1. Definition of the survey content.

Domain	Item	Sub Item
Occupant Profile	Age, Gender, BMI, Type of Work, Type of Shift, Time in the Office, Density of People, Seniority Control options of Indoor Environmental Conditions.	
Comfort at Work	Thermal Comfort	Thermal satisfaction when it is hot/cold outside Description of the temperature when it is hot/cold outside Factors that affect thermal satisfaction When the temperature becomes a problem
	Acoustic Comfort	Satisfaction with the noise level Factors that affect acoustic satisfaction
	Lighting	Satisfaction with the lighting Factors that affect lighting satisfaction Daylight
	Indoor Air Quality	IAQ Satisfaction Factors that affect IAQ satisfaction
	Workspace	Privacy, safety, cleanliness, external window, layout, interior design Factors that affect satisfaction with the workspace
	Ergonomics	Satisfaction with the comfort of the furniture Factors that affect satisfaction with the comfort of the furniture
	Services and Design in Building	General design, resting space, socialization, safety, cleanliness, connectivity, public transportation, interior design
Health and Well-being	Health	Perception of physical and mental health, and physical activity Frequency in which SBS symptoms, mental health, and sleep disorders are felt Options to improve physical activity
	Support for personal well-being	The balance between personal life and work, optimism, being close to people, feeling comfortable
	Nature	Type of view Connection with nature
	Nutrition	Drinking water Healthy food
	Personal productivity	Influence of environmental conditions when it is hot/cold outside Possibility for development
	Absenteeism	Reasons that affect productivity Reasons

In the study with the definitive case studies, the influence of individual subjectivity on the results was avoided by using a representative sample (it was applied to most workers, even if they did not take part in the Netatmo measurement), validating the tool with experts, using statistical analysis, and identifying any possible bias or influence of the individual subjectivity on the results. However, it is worth highlighting that the tool collects data that reflect personal (subjective) preferences, thus differentiating from tools that assess by following traditional comfort models which mainly follow PMV or ASHRAE.

2.2. Data Collection

The fieldwork was carried out between December 2021 and January 2022, and between July and August 2022, in four office buildings located in Los Angeles (37° S latitude, 72° W longitude) with a warm summer Mediterranean climate (Köppen, Csb); Rancagua (34° S latitude, 70° W longitude) is classified as a warm and temperate climate (Köppen, Csa); and in Talcahuano and Concepción, which although being only 15 km apart (latitude 36° S, longitude 73° W) with the same climate classification (Mediterranean-Oceanic (Köppen

Csb) have differences in their microclimates. The case of Concepción is in a densely built-up area, 600 m from the Biobío River, while the case of Talcahuano is located 300 m from the sea with high humidity and frequent coastal trough.

The average minimum and maximum summer temperatures for Rancagua range between 15.4 °C and 32.5 °C; for Los Angeles, they range between 11.3 °C and 28.8 °C; in Concepción, they fluctuate between 10.9 °C to 22.8 °C; and in Talcahuano, they range between 12.3 °C and 21.4 °C. The minimum and maximum average temperatures in winter are 2 °C and 14 °C for Rancagua, 3.1 °C and 13.2 °C for Los Angeles, 5.8 °C and 13.2 °C in Concepción, and 7.1 °C and 13.3 °C in Talcahuano [25].

All the cases (Figure 2) offer active (HVAC, thermostats) and passive (operable windows and/or blinds) strategies, and the office areas are intentionally chosen based on the administrator's suggestions, considering institutional availability and assuming that face-to-face attendance was back to pre-pandemic levels. The areas studied cover four types of offices: shared offices with separators (SO-A1) and without separators (SO-A2) with occupancy of at least 5 people; smaller shared offices for 2 people (SO-B); and individual and private offices (IO). Although the study focuses on shared offices, it was decided to include an individual office type to see the perceptions of people who "dominate" their space, against ones affected by the decisions of others or vice versa.

(**a**) (**b**) (**c**) (**d**)

Figure 2. Case studies chosen. (**a**) Case A; (**b**) Case B; (**c**) Case C; (**d**) Cade D.

The case studies chosen are relevant since they represent the public sector office-type architecture, which despite being in different climates, does not significantly change its shape, envelope strategies, and air-conditioning systems. Likewise, the interior layout is the same in all the cases, where a section chief has a private office with better conditions, while the team shares a space. In addition, after 14 months in lockdown due to the pandemic, Chilean public sector workers returned to in-person work, while other private sector companies remained under the home office modality, coming into the office just one or two days a week.

2.3. Data Analysis

The analysis is divided into three parts. First, the survey results (322) in the 4 case studies are analyzed, then environmental data (temperature and Co_2) from the 73 selected desks are evaluated, and, finally, the 73 occupant cases are analyzed in depth using demographic factors, spatial layout, and perceived health.

The analysis was made using the IBM SPSS Statistics Software version 25. It is bivariate and exploratory by function since there are several aspects: data understanding, atypical data detection, descriptive and interference type analysis, and association hypothesis tests.

The significance level for the entire study is considered as 0.05, and to review whether there are associations between 2 qualitative (or categorical) variables, the Chi-squared test is used considering two hypotheses: (H0) the two variables are independent, and (H1) the two variables are related. When the significance of the Chi-squared test is less than the significance considered (0.05), there is statistically significant evidence to reject H0, namely, the hypothesis that both variables are independent is rejected. Hence, there is an association between the two analyzed variables.

For the Chi-square test results to be reliable, a maximum of 25% of the cells (from the contingency table or crosstab) must have an expected count of less than 5. If this percentage is greater than 25%, then Fisher's exact test is used to check the existence of an association between 2 qualitative variables. Fisher's exact test has the same hypotheses and interpretation as the Chi-squared test.

The questions answered on the Likert scale (1–7) were recategorized into dummy variables, considering answers from 1 to 4 as a low level (dissatisfaction, no control, in total disagreement, uncomfortable, etc.), and the answers from 5 to 7 as a high level (satisfaction, total control, totally agree, comfortable, etc.).

3. Results

3.1. Participants and Workspace Characterization

A total of 432 surveys were delivered and 322 occupants participated (Table 2). In cases B and C, a similar number of men and women took part in the study, while in cases A and D, the number of women was much higher. The most common age range was between 36 and 54. The office type shows a high tendency to shared typology (90.7%), but with a predominance of without separators.

Table 2. Demographic and office type characterization.

Case	Surveys	Participants	Gender			Age				Office Type			
			F	M	No Response	18–34	35–54	>55	No Response	SO-A1	SO-A2	SO-B	IO
A	32	30	18	5	7	8	13	9	0	6	21	1	2
B	150	115	48	55	12	19	55	34	7	35	54	12	14
C	100	74	38	32	4	22	39	10	3	47	11	8	8
D	150	103	62	33	8	26	60	11	6	67	23	7	6
Total	432	322	166	125	31	75	167	64	16	155	109	28	30
%	100	74.5	51.5	38.8	9.7	23.3	51.9	19.8	5	48.1	33.9	8.7	9.3

Of the people surveyed in cases A, B, and C, between 85 and 95% state full in-person work, while in case D, only 34% work in person, and 65% alternate between in-person and telematic work (allowed by the pandemic status).

3.2. Occupant Perception of the Entire Building

Figure 3 shows images of inside the case study offices. It is seen that case A has the highest number of people sharing the same space (up to 19), and it is this case where occupants have the least control over environmental conditions (Table 3). At the same time, in Case B, where the offices are more limited in size than in the rest of the cases, the control is quite similar in all the environmental aspects consulted, except for noise, which appears as the least controlled in all the cases.

Table 3. Mean and standard deviation of the control perceived by occupants.

	Case	Temperature	Ventilation	Solar Protection	Lighting	Noise
Mean	A	3.64	3.20	3.17	3.44	2.16
	B	4.44	5.03	5.23	5.38	4.10
	C	5.14	4.49	5.09	5.61	3.87
	D	4.29	4.37	4.69	5.18	3.17
SD	A	2.36	2.10	2.50	2.48	1.82
	B	2.26	1.97	2.14	2.06	2.19
	C	1.74	2.20	2.29	1.64	2.30
	D	3.64	3.20	3.17	3.44	2.16

Figure 3. Offices images of the selected case study offices.

From the hypothesis regarding the control occupants can exercise and the influence this has on improving their satisfaction, it can be seen that although this has a direct relationship with the low satisfaction obtained in Case A, for example (Table 4), it is necessary to look further at the design of the office. Occupation by so many people not only generates problems with control but also generates problems regarding the opportunities occupants have in terms of interacting with the elements, such as opening or closing a window.

Table 4. Mean and standard deviation of IEQ satisfaction.

	Case	Thermal	Acoustic	Light	Air Quality
Mean	A	4.77	2.76	4.88	3.52
	B	5.60	4.74	6.17	5.26
	C	6.08	5.12	6.14	5.63
	D	5.44	4.22	5.94	5.16
SD	A	1.67	2.07	1.86	1.81
	B	1.50	1.82	1.15	1.66
	C	1.04	1.68	1.05	1.35
	D	1.66	1.79	1.33	1.54

From the correlative analysis (Table 5), it is seen that when satisfaction with the IEQ criteria is above 5 (Mean), the people tend to manifest greater discontent regarding the productivity perceived along with some negative mental and physical health symptoms.

In all the cases, with different climates, control over temperature is also related to comfort when it is warm or cold outside (corr = 0.526). In all the cases, satisfaction with the noise level and noise control are agents that disturb not just satisfaction with other aspects, such as light and IAQ, but also affect productivity, mental health, and negative symptoms such as insomnia.

In Case A, as expected, the control over lighting is related to satisfaction with lighting (corr = 0.510), but the relationship it has with a higher level of insomnia (corr = 0.542) stands out. Satisfaction with lighting in this case affects self-perceived productivity (corr = 0.450).

Table 5. Statistically significant results of the correlative analysis of the surveys. The cases affected are indicated.

	Case	Control over Temperature	Control over Ventilation	Control over Solar Protection	Control over Lighting	Control over Noise	Daylight Received on the Desktop	Influence of Self-Perceived Productivity
Uncomfortable temperature (warm outside)	A	0.637	0.264	0.007	0.147	0.453	0.118	0.341
	B	0.435 ***	0.439 ***	0.536 ***	0.432 ***	0.332 **	0.096 *	0.095
	C	0.572 ***	0.391 **	0.176	0.316 *	0.432 ***	0.004	0.299 *
	D	0.473 ***	0.407 ***	0.415 ***	0.284 **	0.225 *	0.075	0.199
Dissatisfied with the temperature (cold outside)	A	0.331	0.082	0.274	0.156	0.408 *	0.114	0.191
	B	0.526 ***	0.338 ***	0.383 ***	0.326 ***	0.406 ***	0.062	0.079
	C	0.486 ***	0.314 **	0.215	0.495 ***	0.524 ***	0.028	0.076
	D	0.225 *	0.406 ***	0.329 ***	0.339 ***	0.201 *	0.025	0.194
Dissatisfied with the noise level	A	0.082	0.016	0.102	0.231	0.480 *	0.067	0.291
	B	0.439 ***	0.338 ***	0.208 *	0.281 **	0.575 ***	0.099 *	0.290 **
	C	0.283 *	0.072	0.138	0.325 **	0.477 ***	0.017	0.084
	D	0.106	0.022	0.151	0.064	0.307 **	0.025	0.298 **
Dissatisfied with lighting	A	0.459 *	0.286	0.402	0.510 *	0.604 **	0.609 ***	0.450 *
	B	0.325 ***	0.409 ***	0.211 *	0.437 ***	0.363 ***	0.180 ***	0.086
	C	0.175	0.107	0.066	0.119	0.244 *	0.092	0.091
	D	0.174	0.362 ***	0.322 **	0.401 ***	0.255 *	0.185 ***	−0.112
Dissatisfied with IAQ	A	0.289	0.123	0.335	0.445 *	0.706 ***	0.286 *	0.243
	B	0.355 ***	0.361 ***	0.281 **	0.323 ***	0.347 ***	0.142 ***	0.085
	C	0.265 *	0.289 *	0.146	0.325 **	0.196	0.064	0.098
	D	0.395 ***	0.484 ***	0.393 ***	0.332 ***	0.345 ***	0.128 **	0.043
Perceived mental health	A	0.281	0.363	0.237	0.285	0.256	0.028	−0.074
	B	0.098	0.136	0.237 *	0.15	0.257 **	0.061	0.116
	C	0.247 *	0.044	0.182	0.314 **	0.236*	0.032	0.171
	D	0.193	0.19	0.165	0.148	0.088	0.047	0.053
Felt happy over the last month in the building	A	−0.080	−0.223	−0.328	0.206	0.046	0.072	−0.195
	B	0.081	0.096	0.162	0.303 **	0.132	0.083	0.066
	C	0.122	−0.06	−0.076	0.176	0.018	0.028	0.022
	D	0.277 *	0.201	0.1	0.157	0.023	0.074	0.051
Felt sociable during the last month in the building	A	−0.432 *	−0.380	0.076	−0.443 *	−0.253	0.063	−0.250
	B	−0.223 *	−0.058	−0.165	−0.083	−0.275 **	0.067	0.028
	C	−0.124	−0.124	0.015	−0.348 **	−0.137	0.114	−0.096
	D	−0.134	−0.048	−0.085	−0.171	−0.092	0.022 *	−0.215 *
Problems sleeping at night	A	0.109	0.290	−0.024	0.542 *	0.355	0.055	−0.138
	B	0.254 **	0.320 ***	0.304 **	0.360 ***	0.302 **	0.008	0.196 *
	C	0.270 *	0.076	0.158	0.269 *	0.320 **	0.042	0.046
	D	0.243 *	0.190	0.118	0.156	0.128	0.011	0.2
Feels they can do their work well in their main space	A	−0.138	−0.138	−0.138	−0.138	−0.138	−0.138	−0.214
	B	−0.238 *	−0.224 *	−0.365 ***	−0.274 **	−0.324 **	0.151 ***	−0.269 *
	C	−0.183	−0.192	−0.058	−0.271 *	−0.222	0.072	−0.051
	D	−0.063	−0.183	−0.153	−0.168	−0.061	0.043	−0.317**

* Indicates that the relationship between the result and that particular variable has 90% confidence; ** indicate 95% confidence; and *** means 99% confidence.

In Case B, the level of insomnia is present transversally on being linked to control in all aspects. Likewise, productivity would be associated, although slightly, with higher levels of insomnia. The occupants manifest that it is difficult to do their work well, as from the results it is seen that, in general, they need to control everything to be well. In this case, it is seen that the satisfaction with lighting ($\varepsilon 2 = 0.092$) is related with the level they are discouraged ($\varepsilon 2 = 0.117$) or happy ($\varepsilon 2 = 0.122$). Control over ventilation is important for comfort when it is hot outside (corr = 0.439), and with satisfaction with thermal conditions when it is cold outside (corr = 0.338). It is also important when a higher level of insomnia is manifested (corr = 0.320). To a lesser extent, feeling able to do a good job (corr = −0.224) is also important.

In Case C, the control over solar protection is not related to any factor. However, on making the study in the summer, it is observed that all the offices close the blinds, despite having fixed latticework on the facades. This case is where control over lighting is related to different aspects: satisfaction with thermal conditions when it is cold outside (corr = 0.495), satisfaction with noise level (corr = 0.325), satisfaction with air quality (corr = 0.325), rating a better mental health (corr = 0.314), a lower level of sociability (corr = 0.348), a higher level of insomnia (corr = 0.269), and a lower level regarding feeling able to do a good job (corr = 0.271).

In Case D, control over solar protection is related to comfort when it is hot outside (corr = 0.415), satisfaction with thermal conditions when it is cold outside (corr = 0.329), satisfaction with lighting (corr = 0.322), satisfaction with air quality (corr = 0.3939), with feeling more nervous (corr = 0.271), and with feeling more discouraged (corr = 0.351). The percentage influence of environmental conditions on productivity is related to satisfaction with noise levels (corr = 0.298), to a lesser extent with the sociability level (corr = 0.215), and with the level of feeling able to do a good job (corr = −0.317).

3.2.1. By Office Type

Regarding the type of office and the perceived level of control, it is seen that the ability to control environmental factors is always higher in private offices, with the difference in temperature and noise control being statistically more significant than in other factors (Table 6). In shared offices, more than 50% of the people can control solar protection and lighting. On knowing the control occupants have, depending on the office type they use, it can be determined that the productivity and satisfaction of people in private offices will be much higher (compare with Tables 3 and 4). When there is no control or there is complete control in the parameters consulted for the workplace, there are statistically significant differences in the proportions of satisfaction with the four IEQ criteria.

Table 6. Environmental control options by office type [%].

Office Type	Temperature	Ventilation	Solar Protection	Lighting	Noise
Private	70.3	64.9	73	75.7	56.8
Shared	49.2	50	58.1	66.1	29.4

When comparing design aspects of the space with the type of office, significant differences are perceived regarding the daylight received in the workplace (Table 7). In private offices, the occupants who say that daylight is so much that it becomes annoying are more than twice as many in number as those who perceive the same in shared offices. However, it is contradictory that when consulting whether daylight is sufficient enough not to turn on artificial lighting, people in shared offices confirm this more than in private offices.

Table 7. Perception of daylight received in the workspace [%].

Office Type	Almost Nothing	Little	Enough to Not Use Artificial Light	So Much That I Have to Close Curtains or Blinds
Private	21.6	13.5	27.2	35.1
Shared	16.2	21.7	42.3	15.4

For lighting and the proximity to an exterior window, only people who occupy shared offices with separators manifest a higher level of dissatisfaction. Privacy and security are the factors that have the greatest significance when comparing office types (Table 8). The taste for the interior distribution in the workspace also appears as important, with private offices once more being those that have the greatest satisfaction in this regard (80.6%).

Table 8. Satisfaction association intensity and test for workspace factors.

	Perceived Privacy		Security		Proximity to Exterior Window		Layout	
Number of validated cases	294		287		292		288	
	V (*)	S (*)	V	S	V	S	V	S
Association Test (Chi-Squared)	26.78	0	16.71	0.01	8.35	0.039	12.14	0.007
Association Intensity (Contingency Coefficient)	0.289	0	0.241	0.01	0.169	0.039	0.201	0.007

* V: Value; S: Significance.

3.2.2. By Gender

Few differences are perceived between men and women in terms of satisfaction with the variables consulted, but significant differences are seen for the factors that affect those who are dissatisfied. Regarding work and space management, women are dissatisfied that they do not have enough space for personal items or authorization to customize their workspace, and they also demand better work–life balance and the option of working under flexible work schedules. Meanwhile, men indicate not having enough time to get/eat healthy food, and that the office does not have a designated eating space.

For causes of absenteeism, "harassment or intimidation" and "caring for a relative" are lower in men than in women (1.3–2.5% and 17.5–26.2%, respectively).

3.2.3. By Level of Control over Environmental Conditions

When there is either no or complete control over workplace temperature, there are statistically significant differences in the thermal satisfaction percentages if it is hot and cold outside, with slightly more impact in the summer (Table 9). This also happens with complete control over ventilation, positively affecting IAQ satisfaction, and the same occurs with lighting satisfaction. Meanwhile, for noise control, it is observed that although satisfaction increases with control, it is not as much as in the aforementioned factors, and when there is no noise control, the numbers satisfied with the noise level decrease compared to those satisfied with other IEQ factors when having control of these. That is to say, on not having control over the temperature, ventilation, and lighting, at least half of the people state being satisfied, while if they do not have control over the noise, only 40.8% are.

Table 9. Satisfied and dissatisfied occupants with IEQ by the level of control [%].

Level of Control	Temperature		Ventilation		Solar Protection		Lighting		Noise	
	D (*)	S (*)	D	S	D	S	D	S	D	S
No control	39.7	60.3	47.9	52.1	47.9	52.1	28.0	72.0	59.2	40.8
Complete Control	4.8	95.2	11.6	88.4	16.8	83.2	5.2	94.8	22.4	77.6

* D: Dissatisfied; S: Satisfied.

3.2.4. Factors That Affect Satisfaction

Only the responses of dissatisfied occupants were chosen to determine those factors that affect them. In the thermal performance, the "morning (<11 am)" and "afternoon (2 pm–5 pm)" schedules are the most unsatisfactory for both summer and winter, and the determining factors are: little air movement in summer (57.8%), the thermostat is adjusted by someone else (51.6% in summer and 51.1% in winter), the air-conditioning system does not work properly (42.2% in summer and 39.8% in winter), not having access to open the window (31.3%), and too cold in winter (38.6%)

Regarding noise level, the factors that cause dissatisfaction are people talking nearby (83.0%), noises outside the building (35.5%), and equipment noise (34.8%). For lighting satisfaction, the predominant factors are there is not enough daylight (43.2%), and I cannot control the amount of light on me (35.1%). As for ergonomics, the factors indicated are the chair is uncomfortable (48%), difficult access to electrical points (48%), the height of the chair and/or desk cannot be adjusted, and there is not enough space to move around freely (33.3%).

3.2.5. Biophilia

When comparing satisfaction with different factors between people who only see nature from the nearest window and those who can only see buildings and/or parking lots, it is observed that the satisfaction level is higher in all IEQ aspects in the former, but it is considerably higher in the noise level (Table 10). This may be due to the silence and visual tranquility that a natural environment provides. The occupants who can see nature are more satisfied with the type of view, while the difference with the other group of occupants is not as high as expected. However, when asked about the level of importance they give to the outside view, the group of 60.4% satisfied with the view of parking lots increases to 90% of people who care about what they see from their workplaces.

Table 10. Satisfaction, level of perceived health, and importance of view seen from the window [%].

	Satisfied						Good Perception		Important
	Thermal Conditions	**Noise Level**	**Lighting**	**IAQ**	**View Outside**	**Comfort of Furniture**	**Physical Health**	**Mental Health**	**View Outside**
Only see nature	83.3	91.7	91.7	83.3	75	50	58.3	66.7	100
Only see buildings, streets, and/or parking lots	73.1	49.3	88.1	67.9	60.4	67.9	72.4	63.4	90.3

The relationship of view type with difficulties sleeping well at night does not show a great impact, nor does the control they have of solar protection. However, it is more significant when comparing these symptoms to lighting control: the level of sleep problems increases considerably by increasing the number of occupants without lighting control in their workplace (Table 11).

Table 11. Comparison of sleeping difficulties to occupant's control over lighting [%].

Trouble Sleeping	No Control	Total Control
None	17.6	82.4
Mild	33.3	66.7
Moderate	26.7	73.3
High	41.5	58.5

3.2.6. Health and Control of Environmental Factors

There is an indirect or inverse association between the symptoms of choking when breathing and control over work environment temperature, namely, the greater the symptom, the less control over the temperature. The same happens with the symptoms of choking when breathing and coughing and control over ventilation, solar protection, and lighting in the work environment.

Those who report suffering from headaches at work have limited control over solar protection and lighting in the work environment. In total, 83% of occupants who do not have control of the workspace temperature and 85% who cannot control the ventilation have headaches while working in the building.

Those who indicate that they perceive their eyes to be drier or itchy at work mark having less control over the temperature, ventilation, solar protection, and lighting in their office.

A dry throat, meanwhile, could be related to limited ventilation control. This control, together with limited control over temperature, also affects symptoms of nasal congestion, sneezing, dizziness, or lightheadedness while the person was working in the building.

For difficulties remembering things or concentrating while working in the building, statistically significant differences are found in the proportions with control over ventilation and noise.

3.2.7. Productivity

Of the occupants who report perceiving a decrease in their productivity when it is hot outside, only 23.3% indicate being dissatisfied with the thermal conditions during summer, while for those who perceive a decrease in their productivity in winter, the number increases to 48.8%.

3.3. Environmental Layout of the Offices

In all the cases, it is observed that during the working day, temperatures fluctuate inside and outside the suggested temperature range for Chilean public buildings [26]: 19–22 °C in winter and 22–24 °C in summer. The same reference indicates that the CO_2 level should be below 1000 ppm in at least 80% of occupancy times, and in the analyzed cases, only Case D complies with this, even though all cases except A (Mean: 3.52), show a satisfaction higher than 5. In all four cases, it is observed that indoor temperatures are higher than outdoor temperatures in winter, as well as in summer, except for Case A, where indoor temperatures are similar to the minimum outdoor averages recorded. However, if the scales of satisfaction with the temperature at this time are viewed, there is an average of 5.7, which reinforces the idea that the temperatures set as standard are not necessarily those that the user considers for their satisfaction.

In all cases, CO_2 levels increase in winter, being more extreme in Case B where they double, and where, on the contrary, the temperature remains within similar ranges if both seasons of the year are compared (Figure 4). If the measured data are analyzed based on the spatial layout of the offices and how occupants are located, it is seen that CO_2 increases noticeably in winter in office 1, where half the glazed surface with openings is shared by five users, while the other half is inside a private office occupied by the section chief (occupant 5). This person spends part of the day going around the building, closing the door, and the air is not constantly renewed. In this office, occupant 6 is the most affected in terms of air quality. Although this is a private office with HVAC, it has no window to the outside and the occupant does not usually turn on the equipment.

In office 3, with north-facing windows, it is observed that temperatures are higher than in the other offices and that the area shared by six users registers the highest temperatures. On the other end of the scale, workstations 14, 15, and 16, which are located next to the window, record the highest average minimum temperatures. In office 2, it is observed that user 10, who has an individual office, maintains the most neutral temperature because of access to an air-conditioning system. This is consistent with what the user indicates on being surveyed, since in summer and winter, 7 is indicated for the satisfaction level. When analyzing the survey of occupant 5, where the lowest temperatures are recorded, the user declares being completely satisfied (7), which does not coincide with what is standardized in Chile, since the temperatures are between 18 and 20 °C and not between 19 and 22 °C.

When observing occupant 13, whose desk sees the highest temperatures in summer, it is observed that they rate their satisfaction with a 2, which is consistent with the conditions measured and observed in the mid position they have in the office, only adjoining other offices and a corridor.

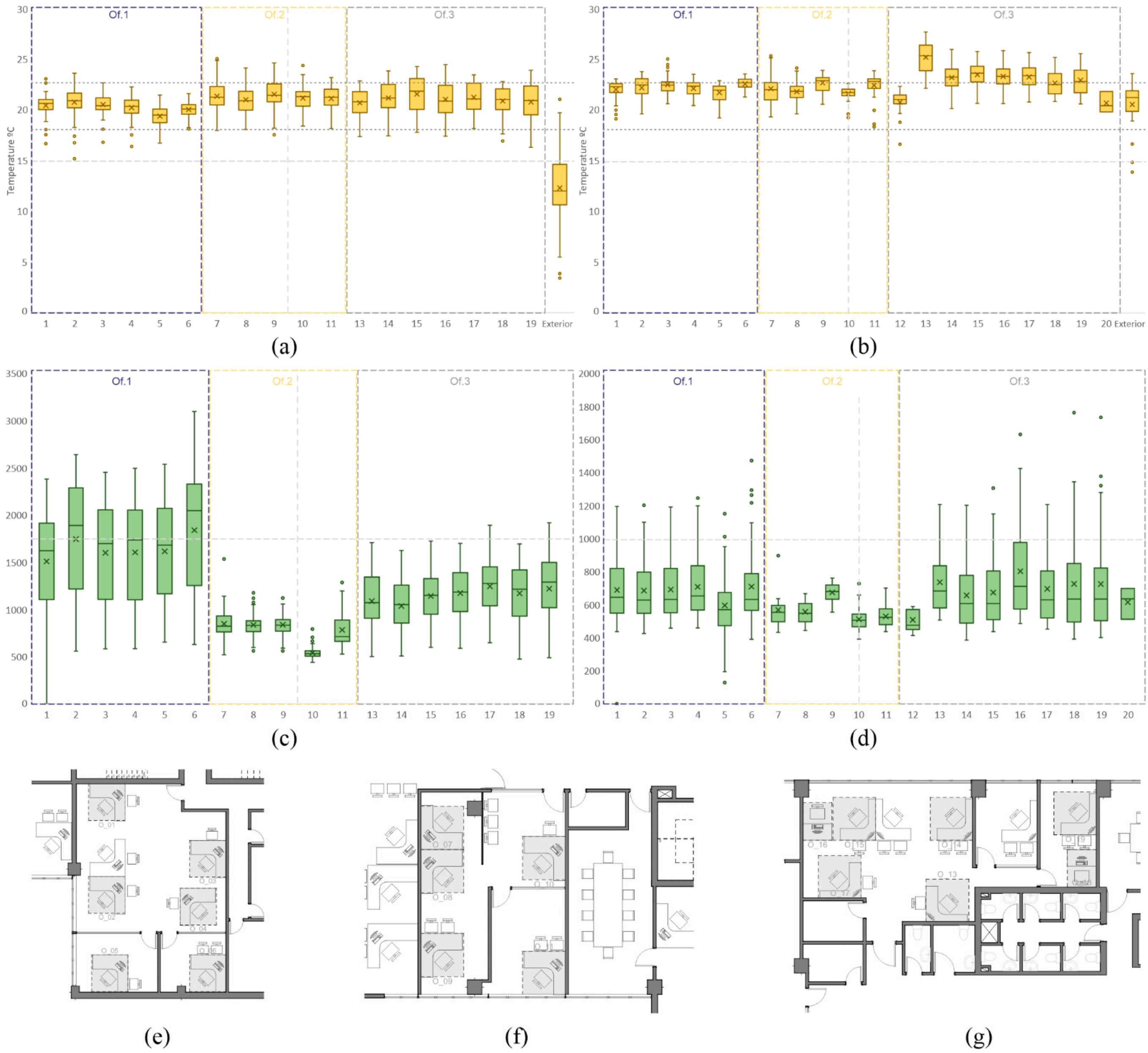

Figure 4. Temperatures and CO_2 levels obtained for each office in Case B: (**a**) temperatures in winter; (**b**) temperatures in summer; (**c**) CO_2 in winter; (**d**) CO_2 in summer; (**e**) office 1; (**f**) office 2; (**g**) office 3.

The data recorded are not the only parameters required to understand differences in the needs of people living in the same space, since there is a wide variety of possible drivers that generate different requirements, with some factors more relevant than others. Being able to know the true drivers of diversity would be useful to generate new user-chosen thermal conditions, affecting not only energy consumption, itself a driver of climate change, but also the health, well-being, and productivity of the occupants [27].

3.4. Relationships between Spatial and Human Factors, and Occupant Perception

This section analyses the responses of occupants who took part in environmental measurements and whose actions and spatial characterizations of their workplaces were observed.

3.4.1. Spatial Layout

Table 12 shows the summarized results of the correlative analysis between spatial variables and the perceptions regarding comfort at work, health, and well-being. The type of grouping has the highest significance, highlighting the impact this has on satisfaction regarding space and its design, as well as on mental (nervousness) and physical (back or neck pain) health symptoms. This seems logical when occupants have adjoining desks that limit views, privacy, and the option to decorate their own space.

Table 12. Correlative analysis of significant values between spatial and satisfaction variables, and occupant health and well-being.

	Level	Distance from the Window	Type of Grouping	Desk Space
Daylight received on the workspace	0.485 **	−0.497 **	−0.365 **	0.262 *
Satisfaction with IAQ	0.309 **	0.010	−0.313 **	0.142
Satisfaction with window proximity	0.426 **	0.439 **	−0.225	0.100
Satisfaction with view from the window	0.482 **	−0.664 **	−0.336 **	0.159
Satisfaction with interior layout	0.203	−0.220	−0.328 **	0.280 *
Satisfaction with decoration	0.282 *	−0.063	−0.508 **	0.342 **
Dissatisfied with work surface	−0.455 **	0.074	0.331 **	−0.262 *
Dissatisfied with safe space for personal items	−0.154	0.135	0.357 **	−0.176
Satisfaction with ergonomics	0.077	0.028	−0.405 **	0.166
Satisfaction with the design	0.225	−0.186	−0.335 **	0.244 *
Feels back or neck pain	0.338 *	0.105	−0.497 **	0.197
Dry or irritated eyes	−0.105	−0.048	0.261 *	−0.055
Feels nervous	0.289	−0.116	−0.387 **	0.010
Feels optimistic	−0.109	0.321 **	−0.067	0.043
Type of window view	0.350 **	−0.280 *	−0.307 **	0.141

*: 90% confidence. **: 95% confidence.

The level where the occupant is and their proximity to a window have an impact in terms of IAQ, lighting, and views, which may be obvious, but it does affect their satisfaction. The space provided in the workplace directly affects satisfaction regarding decoration and interior layout, but it does not affect satisfaction with the environmental quality or the generation of negative health symptoms.

There is no association between being close to an exterior window or not with IEQ satisfaction. However, an average association is observed between the distance to the window and the presence of dizziness or light-headedness symptoms, since people report feeling them at work, and 76.9% have no control over natural ventilation.

On differentiating occupants using their distance from the nearest window, no significant differences are observed in the control they perceive having over elements that can regulate temperature, solar protection, and noise. Although they may have the opportunity, they do not take the action, contrary to what was pointed out by [28], whose findings indicate that the distance to the window is as closely related to the performance of the action as to the perceived opportunity, and that the shorter the distance, the greater the probability of being active or perceiving the opportunity.

From the relationship between the orientation of the nearest window and satisfaction with thermal conditions, it is observed that there is an average association if it is cold outside. In the east and west orientations, there are statistically significant differences in the proportions of thermal satisfaction if it is cold outside (Table 13).

Table 13. Satisfaction by nearest window orientation.

Window Orientation	**Satisfaction with Thermal Conditions in the Workspace If It Is Cold Outside**	
	Dissatisfied	Satisfied
North	5a 31.3%	11a 68.8%
South	1a 12.5%	7a 87.5%
East	3a 12.0%	22b 88.0%
West	4a 66.7%	2b 33.3%
Northeast	5a 50.0%	5a 50.0%
Southeast	2a 40.0%	3a 60.0%

There was no association between window orientation and light satisfaction in the workspace. However, it is important to note that the occupants who have southeast-facing windows are completely satisfied with the lighting in their workspace.

People who occupy desks attached to another desk tend to be more dissatisfied compared to those who have separate desks (69.6% and 11.4%, respectively).

No statistically significant relationships are observed between the location of the HVAC system and people. However, in the field study, certain "strategies" of those who felt discomfort from being too close to the air-conditioning system were seen (Figure 5).

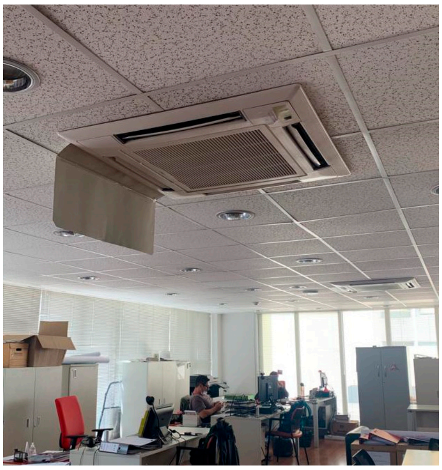

Figure 5. Intervention to the air-conditioning system made by the occupant.

3.4.2. Personal Factors

There are no associations between nutritional status (BMI) and perceived health, or with the factors that influence not eating healthy at work or in thermal comfort, unlike what was indicated by [27,29], who indicate that individual differences in body composition are determinants in people's perception of the thermal environment and that people with a BMI greater than 25.0 prefer cooler environments.

4. Discussion

In a recent study that contrasts 37 research projects on personal comfort models [30], a lack of diversity is identified in the types of buildings used in the evaluations or measurements, as well as in the climatic zones and participants involved in the development of new comfort models. This study includes sociodemographic characteristics, body characteristics, and the type of work and occupation of the worker to develop a broader analysis, identifying challenges associated with personal comfort models for different places and cultural contexts.

All the buildings considered as case studies consider HVAC systems, although it is those located in the most extreme climates (A and C) that use HVAC most consistently, both for winter and summer. However, the differences in thermal satisfaction in these cases with the use of HVAC and similar climates are different, since Case A has the lowest level of satisfaction (Mean: 4.07), while C has the highest (6.08). From the correlational analysis, it is seen that not only climate and HVAC use have an impact, as satisfaction is multivariable and depends on other factors that positively or negatively stimulate the occupant.

The predominant negative factors found in Case A to make users feel dissatisfied in terms of thermal performance are as follows: limited access to control of the air-conditioning system and to open windows, limited temperature stability during the working day (Mean: 3.84, on a scale of 1–7), little air movement and how hot and cold it feels (assuming that the climate system is insufficient). In the most current certification systems, such as WELL or Leed v.4.1, providing the user with the ability to control the physical environment is "rewarded" but not mandatory. However, it has been shown that if the occupant can individually choose which indoor environmental parameter to modify, it will cause a significant effect on their tolerance regarding comfort, making this and satisfaction increase [24,31,32]. For future research, it would be necessary to address the psychological effects of perceived control further, since these may not be solely due to changes in physical conditions, altering the modeling approach that is intended to be designed for a broader population [27].

On the other hand, most models that regulate current building design strategies are based on the simplistic assumption that human beings react in a disjointed and monotonous way to the stimuli they are exposed to, namely, that there is a dose-response relationship between exposures and experiences. In fact, research and post-occupancy evaluations (POE) have mainly addressed and examined IEQ factors separately, expressing objective associations between stimuli and responses [33], without taking into account possible interactions between parameters, influences of cross-modal stimuli [34–36], or the diagnosis of the combined effects on occupant well-being and health, which is barely noticeable in the basic concepts of conventional standards and certification systems.

If other factors that may be negatively impacting occupant thermal satisfaction in Case A are cross-checked, it is seen that their satisfaction with lighting, air quality, proximity to a window, the available workspace, and the ergonomics of the workplace is considerably lower than in the other cases, while they state that they do not like the lack of acoustic and visual privacy, the decoration, spatial layout, and the view from the window. In this case, 48% state receiving almost no daylight in their workspaces, which is coherent with [37], who conclude that the amount of daylight influences people's thermal perception, specifically resulting in a multimodal effect, with low daylight illuminance leading to a less comfortable and acceptable thermal environment.

In all cases, the temperatures at certain times of the day are outside a standard comfort range. However, a large percentage of occupants of all cases, except A, state being very satisfied with the temperature. In particular, in Case C, occupants express satisfaction with the available workspace, ergonomics, perceived humidity, flexible clothing option, spatial layout, indoor and outdoor security, and the general design of the building. That is to say, certain factors are acting positively, making people "forgive" certain non-ideal conditions. Although satisfaction with the noise level is not the highest evaluated in this case, there are fewer complaints than in the other three cases. Only 50% of people are annoyed by people talking nearby, while in the other three buildings, between 60.5 and 88.5% are. The impact of acoustics, as noted by [38], can increase or decrease thermal satisfaction and comfort, which, for example, increases with a decrease in the noise level (from 75 to 35 d) and in brighter conditions, as occurred in this case study.

How offices are designed is fundamental within this multivariate satisfaction. For example, the available workspace is relevant, both as a negative or positive stimulus influencing job satisfaction in general, regardless of the age group and gender of the building's occupants, office type, or distance of the workstation to a window [39]. In all the cases evaluated, the type of view from the window positively affects satisfaction in all aspects of IEQ, but it is even greater for satisfaction related to the noise level, which can be explained by the perception of tranquility and silence that a natural environment provides.

The search for comfort and increased personal satisfaction in the work environment translates into dynamic needs that drive certain occupant responses or actions (adjusting the thermostat, opening a window, turning off a light, etc.) to meet their needs in a given space and time ("right here, right now"), without considering short- and/or long-term well-being and health. In Case A, the occupants report perceiving more negative physical and mental health symptoms while in the building. A negative influence of the distance to the window is observed, since as the distance grows, so does the presence of dizziness or lightheadedness symptoms, thus being able to assume that this low satisfaction is caused by poor indoor environmental conditions that also cause short-term illnesses, without knowing the long-term effects.

Regarding self-estimated productivity, the study is consistent with what has been found in other research [40], since the occupants of Case A, who feel uncomfortable with indoor environmental conditions, report a decrease in their productivity, especially in unfavorable thermal conditions.

For office types, the occupants of private offices receive more than twice the daylight if compared with people who share spacious offices, especially those with partitions. Satisfaction regarding noise level or acoustic privacy is noticeably higher in private and individual offices, lower in offices shared by fewer people, and considerably lower in offices shared by more than five people, coinciding with the conclusion by [39]. It can be concluded then, that as other authors have pointed out (see Section 1), it is not enough to have ample spaces to promote productivity, better relationships between colleagues and creativity, but rather flexible and adaptable spaces must be provided by the physical and environmental conditions to satisfy occupants and reduce negative physical and mental health symptoms.

It is seen that many respondents do not have access to control environmental conditions, either for the entire office or personal devices, negatively affecting their satisfaction and the detection of negative health symptoms, such as the perception of dry eyes and sleep issues. Contrary to other research, in the case studies it is revealed that proximity to the control element is not decisive when generating an action.

Given the current generalized use and operation of HVAC control systems and the limited control or personal comfort options there are for people who share the same space throughout the day, two main important problems are noticed to be addressed by future research directions:

- HVAC systems are designed to condition entire spaces, regardless of whether partially or fully occupied (wasting energy); despite being regulated and configured by optimal comfort criteria, they fail to satisfy occupant requirements, mainly due to the differences each individual has that do not fit the average used to define the criterion.
- There is a lack of integration of criteria that affect people's health and well-being in comfort models. Normally, the term well-being is used interchangeably as "health", "quality of life", and/or "comfort", but the requirements and characteristics of each are different. There are substantial discrepancies between what people need to perform their "transient" activities (comfort), and what they need to feel good and be healthy over time (well-being).

5. Conclusions

The results presented evidence that the satisfaction of people is multivariable and will depend on other factors that positively or negatively stimulate their sensations and perceptions, and demonstrate that it is not enough to reach IEQ's high standards if these do not include other relevant aspects that complicate the design equation. In terms of design, it is necessary to define other ways to group workplaces, for example, with isolated distributions that allow the occupant to feel more satisfied and healthier.

On the other hand, following globally used thermal comfort standards (PMV, ASHRAE) does not guarantee occupant satisfaction, especially on these not including indoor health issues. Some occupants, despite being satisfied with the temperature, manifest general dissatisfaction, as the satisfaction regarding noise levels affects their overall perception of the workspace. Likewise, it was seen that having limited control over the noise level affects the perception the occupant has for other areas, such as satisfaction with temperature, lighting, and air quality.

By comparing the results of the surveys, it is seen that when people state being more satisfied with environmental aspects, higher discontent with the productivity perceived and some negative mental and physical health symptoms abound. This is coherent with what was outlined in this research; occupants may be comfortable and/or satisfied, but do not know the implications that the strategies used to reach this goal could have on their health and well-being.

On the other hand, on measuring the temperature and CO_2 levels in the workplace, it is seen that there is a group of people who state being satisfied, even though they are outside the comfort range. This shows that occupants can be more tolerant or "forgive" less-than-ideal conditions, as long as they are offset or compensated in some way. This is why positive stimuli are so important to consider as a complement, as opposed to just avoiding negative stimuli in the design of office spaces.

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