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A survey-based approach used to analyse the indoor satisfaction and productivity level of user in smart working during lock-down due to the COVID-19 pandemic

Francesco Salamone[1*], Lorenzo Belussi[1], Ludovico Danza[1], Italo Meroni[1]

1 ITC-CNR, Construction Technologies Institute, National Research Council of Italy, Via Lombardia, 49, 20098 San Giuliano Milanese (MI), Italy

* salamone@itc.cnr.it

Abstract. Italy was the first country in Europe to enter lock-down due to COVID-19 pandemic. Most employees have been forced to adopt a work at home solution to avoid any possibility of spreading the virus. The article presents the results of a survey carried out in March-June 2020, during the first lockdown in Italy, aimed at investigating how people perceive the Indoor Environmental Quality (IEQ) of their households during working from home. The questionnaire consists in a general section reporting information about participant, households and rooms where they perform the working activities; a specific section reporting feedbacks on each IEQ aspects (thermal, visual comfort, air and acoustic quality), overall comfort, productivity and other external variables that can affect users' well-being during working hours. A total of 330 participants from all over the Italian territory signed the consent to participate in the survey over a period of about 3 months. The dataset was used to define the global level of satisfaction, perception, preference and interference with work at home, considering the main indoor environmental factors. The Machine Learning (ML) approach was applied to identify the most useful model to predict the overall comfort satisfaction.

1. Introduction

Besides a catastrophic effect on human health, mortality rate and the economy, the recent Sars-Co-2 pandemic has accelerated the transition toward remote working, i.e. "a situations where the work is fully or partly carried out on an alternative worksite other than the default place of work" [1]. Recent statistics highlight how in all European countries the number of people that work from home has grown, as happened in Italy [2]. This phenomenon has raised several issues that must be faced to identify measures that can guarantee the balance between human health, safety, satisfaction and performance. This article addresses the issue of indoor comfort satisfaction and performance of work at home, during the pandemic. Over the last few decades, several researchers investigated the effects of remote work on people in terms of job satisfaction, performance and well-being. The results of these research are not homogeneous. [3] and [4] found out a disruption in home workers, due to the social and professional isolation, difficulties in communications, changes in social relations. Conversely, [5], [6] and [7] identified a positive relationship between workers' satisfaction level and work at home. Time and money saving is one of the most detected benefits [8]. These studies focused on the situation when work at home is a structured solution where workers are aware and prepared for this kind of condition. Instead, the pandemic has effectively projected millions of workers into this new condition, without specific

training or without the time to adapt their own home. In this context, analysing worker feedback on indoor conditions is important to identify trends, solutions and strategies to improve human well-being and productivity during work at home.

The Indoor Environmental Quality of indoor spaces and its relationship with health and productivity of workers has been investigated by several research projects [9]. These studies have mainly been carried out in office. To the authors' knowledge, the investigation of IEQ during work at home is still a nascent field that today deserves a great attention, due to the change of paradigm in working activities.

The current paper aims at investigating if homes meet the requirement to host working activities and guarantee an adequate level of IEQ and productivity through a web survey on users' satisfaction with work at home carried out during the lockdown in April and May 2020. The survey reported questions about the perception, preference and satisfaction of users with respect to thermal and visual comfort, air and acoustic quality, overall comfort and the way these aspects can affect the productivity. The analysis was conducted with a twofold goal: the former analysing the judgment of people respect to IEQ aspects and productivity during working at home, the latter identifying a model to predict overall users' satisfaction during work at home. For the latter goal, ML techniques were implemented.

2. Materials and methods

The study provided the definition of web survey for the collection of users' feedbacks on their personal comfort and productivity during work at home. The questionnaire was designed following the consolidated approach defined by international standards [10] extending the scope with the inclusion of home spaces and home workers', with the aim of identifying the variables that can affect user satisfaction during home officing. The questionnaire was designed with the Microsoft Forms platform and made available via web [11]. It is divided in different categories. The first one is an authorization to use the responses for scientific purpose in compliance with the General Data Protection Regulation GDPR 2016/679. Each environmental factor is investigated considering satisfaction, perception and preference through Categorical Scales (CS) with different points and directions (Table 1). The 5-points CS of satisfaction is the same for all considered factors.

Table 1. Categorical Scale used in the questionnaire.

Environmental factor	Satisfaction	Preference	Perception
Thermal comfort		Bipolar 3-points CS	Bipolar 7-points CS
Visual comfort		Bipolar 3-points CS	Bipolar 5-points CS
Acoustic quality		Unipolar 4-points CS	Unipolar 5-points CS
Indoor air quality		-	Unipolar 4-points
Overall satisfaction	Bipolar 5-points CS	-	-
Available space		-	-
Furniture and complements		-	-
Visual privacy		-	-
Acoustic Privacy		-	-
Productivity		-	-

The questionnaire was distributed to civil servants, including university staff and private employees, that mainly perform office activities. Each participant accepted to be part of the survey giving their consent to the use of the answers provided for scientific purposes. A total of 330 employees participated in the survey. The sample consists of 56% females and 44% males, aged between 26 and 65. 39% of participants are in the age range 36-45, 30% in the range 46-55, 19% in the range 26-35 and 12% in the range 56-65. More than 40% are public employees (including researchers and administrative staff), about 30% are private sector employees, 14% are university researchers or professors, and 12% are freelancers, generally with a high level of education: 74% report master's degree and 25% a high school

diploma. 75% of participants had been working at home for more than 1 month and 22% for more than 2 weeks. The survey shows that only 19% of the participants perform their work activities alone, more than 80% share the spaces with other family members. 38% share their work life with one or more children. 72% of the participants live and work in apartments. About 45% in houses built before 1976, which in more than 55% of cases have not undergone major renovations in the last 10 years. 40% carry out their work activities in the living room and in 78% of the cases less than 2 meters from a window. The size of the rooms used is mostly between 10 and 25 m2. The time spent in these rooms is between 6 and 9 hours for 71% of the respondents. To ensure adequate ventilation, 44% of users open windows for more than one hour per day and 55% for more than 10 minutes. In 49% of cases, users also use window blinds to ensure visual privacy.

The information collected with the questionnaire was analyzed with statistical approaches. The non-parametric Spearman test was used to evaluate the correlation between the different variables identifying their strength respect to the target feature, i.e. the overall satisfaction. The prediction of the overall comfort satisfaction was performed using five different ML supervised algorithms: LSVC (Linear Support Vector Classifier), kNN (K-Nearest Neighbors), SVM (Support Vector Machines) and two of the most used ensemle classifiers, the GBC (Gradient Boosting Classifier) and the XGB (eXtreme Gradient Boosting).

3. Results

3.1. Descriptive analysis
Figure 1 shows the distribution of subjective responses related to satisfaction, perception, preference and interference with productivity. More than half of participants are "Satisfied" and "Very satisfied" with the home spaces, with the lower value recorded on acoustic quality (68%) and the highest on thermal comfort (89%). In thermal, visual and IAQ satisfaction the mean values of the answers is ≥ 1.0 ("Satisfied" category) where: TC = 1.2, VC = 1.0, IAQ = 1.0. Mean acoustic satisfaction is equal to 0.8. The overall IEQ is satisfying for 85% of participants with a mean value of 1.1. This trend is further reflected in the survey on perception and preference where more than half of participants requires no changes in the environment and a neutral perception. In thermal and visual preference, 288 and 246 participants answer no need for change, respectively. In acoustic preference, 166 answers are "no change" and 109 "Slightly quieter". From the perception point of view, two-third of the sample feels the thermal and visual environment "Neutral" (mean = 0.0 and -0.2, respectively). The acoustic quality reaches a mean value of 2.6, between "slightly noisy" and "Quiet". Finally, the IAQ mean perception is equal to 0.3, between "not smelly" and "slightly smelly".

The answers related to the room layout and equipment follow a similar trend with more than half of the participants satisfied. The lowest satisfaction is recorded for the "comfort of Furniture" category (M = 0.4). This is a consequence of the lack of time to adapt the households to working at home activities. Most of the participants state that the environmental aspects positively interfere with the ability to perform the working activity.

In general, the feedback expressed by participants reflect satisfaction toward the indoor environment during work at home. Several studies analyse the satisfaction of users in offices. In [12] and [13] the office layout and the desk location are the most influential factors of thermal and light comfort. In [14] and [15], people in offices are mainly satisfied with ease of interaction, amount of light, maintenance and furnishing. Conversely, noise level, temperature, sound and visual privacy cause dissatisfaction. In the current survey, all the features explored (thermal, visual, light, acoustic and overall satisfaction) show a "positive" trend, meaning that the mean satisfaction values are placed in the "satisfied" of "very satisfied" votes. In surveys carried out in offices some factors related to thermal and acoustic domains cause dissatisfaction in users. In work from home, where workers can adapt their workstation to their need in relation to environmental parameters (light, temperature, etc.) and where they can control their privacy, the satisfaction with these aspects is high. On the other hand, the furnishing is not adequate in many cases in comparison to work at the office.
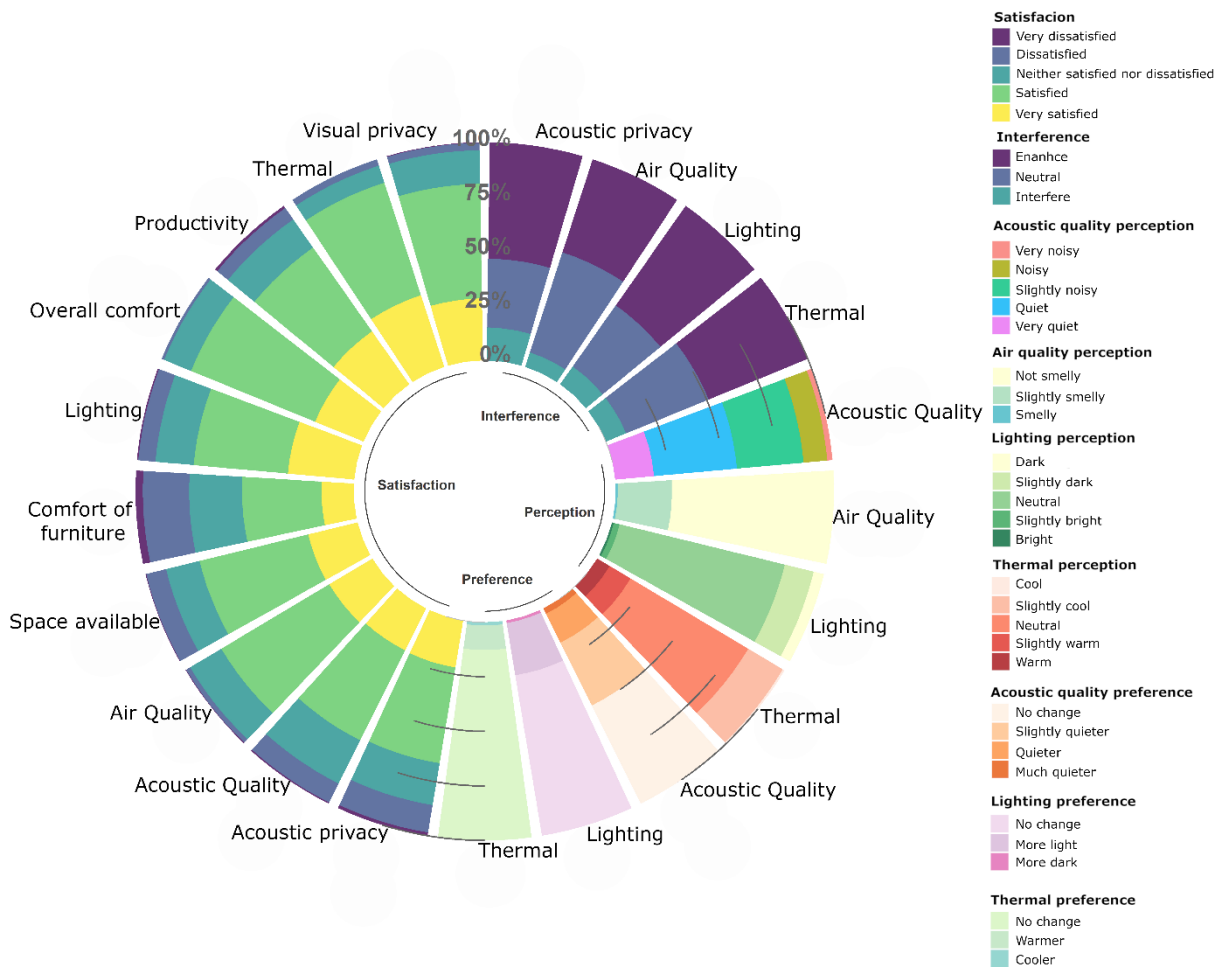
Figure 1. Distribution of subjective responses.

3.2. Predictive analysis

The application of the non-parametric Spearman test was used to investigate the correlation between each variable and the overall comfort satisfaction. The results of the test show a general low correlation excluding interdependences among the variables. The highest values are reached for indoor air quality and thermal comfort, with a coefficient ρs (a nonparametric measure of rank correlation. It measures the strength of association between two variables in a single value between -1 and +1) equal to 0.366 and 0.350 respectively, highlighting a low positive correlation with overall satisfaction. In the ML approach, variables with low statistical significance play a minor or no role in assessing predictive performance. For this reason, all variables of the questionnaire [11] are included in the predictive approach and are used with the main goal of identifying which model and features are the best at predicting the overall indoor satisfaction. For this purpose, three classes (Very satisfied, Satisfied and Neither satisfied nor dissatisfied) were considered, while the "Dissatisfied" option was not considered because it only comprises 1% of the total data (Figure 1).The "F1-score" metric was used to evaluate the different algorithms because it is the most used when learning from imbalanced data. It is defined as the weighted average of the precision (defined as a measure of a classifier's exactness) and recall (considered as the completeness of the classifier). The stratified k-fold cross-validation (number of splits = 10) is used to evaluate the performance of the different algorithms. Figure 2 shows the average F1-score and the standard deviation for the different considered models.
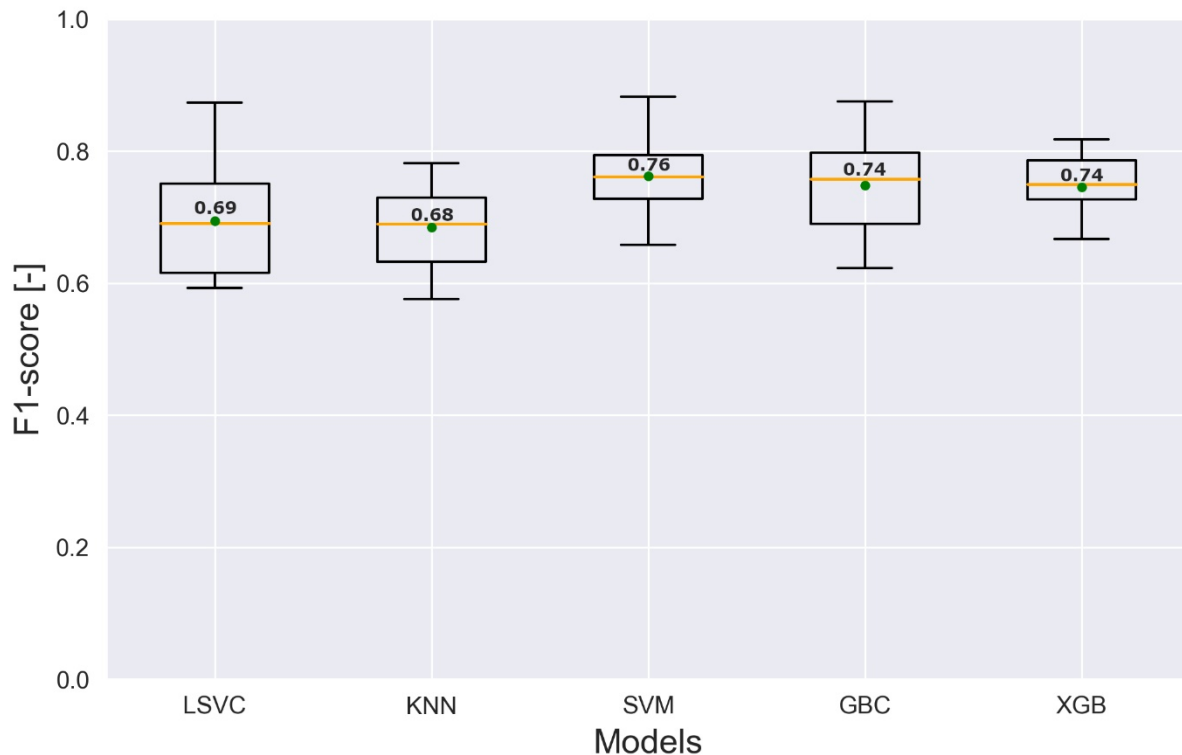
Figure 2. F1-score for the different models.

The SVM based-model slightly exceeds the GBC and XGB models and it has the highest average F1-score (0.762 ± 0.064).

4. Conclusion

The study investigated the satisfaction of people during work at home in relation to the quality of the indoor environment, including IEQ aspects and other variables that can affect the productivity. The results show that more than half of participants are satisfied with the quality of the spaces where they perform their working activity. The possibility to adapt the indoor spaces to their needs, for example opening windows, increase the perception of indoor comfort. Acoustic quality is the critical aspect due to the difficulty to implement action to reach adequate level of comfort.

Among the four considered factors, there is not a most relevant variable in relation to the interference with the productivity. The comfort of furniture seems to have a negative impact on the satisfaction of participants, with 45% of users expressing an unsatisfactory or neutral opinion. The predictive approach identified the SVM-based model as the most promising to predict the overall satisfaction.

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