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Rethinking comfort
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The assessment of the environmental quality directly perceived and experienced by the employees of 69 European offices

A. Marchenko[1,*], S. Carlucci[1], L. Pagliano[2], M. Pietrobon[2], T. Karlessi[3], M. Santamouris[3], N. Delaere[4] and Margarita Assimakopoulos[3]

[1] Department of Civil and Environmental Engineering, NTNU Norwegian University of Science and Technology, Trondheim, Norway.
[2] Department of Energy, Politecnico di Milano, Milano, Italia.
[3] Department of Physics, University of Athens, Athens, Greece.
[4] Factor4, Antwerpen, Belgium.
[*] Corresponding author email: alla.marchenko@ntnu.no, phone: (+47) 936 29701

Abstract: A number of scientific studies have shown that the performance capacity and employees' satisfaction, enjoyment and health are directly affected by how building occupants perceive the environmental conditions that characterize their working environment. The physical well-being and comfort perception of employees directly impacts their productivity and satisfaction. However, several researchers have shown that, in numerous office environments, indoor environmental conditions are far from being perceived as comfortable. Often the main causes are faultily commissioned and operated building management systems, the lack of appropriate and coherent quality management procedures and errors in design or construction of the building systems. In order to identify critical conditions and provide a set of improvement measures, a data collection and analysis tool has been developed. It is called *Comfortmeter* and is used, in this paper, to analyze 69 office environments distributed throughout Europe. The tool enables the evaluation of the performance of a building as directly experienced by its occupants. The evaluation covers the themes of thermal, visual and acoustic comfort, indoor air quality, individual control possibilities and the quality of the office environment. It provides detailed outcome and practical advice to create a healthier working environment for employees. In order to use the tool, it is required, first, to administrate an online survey among the employees. Then, the employees' responses are gathered and stored in a database. Next, the stored data are statistically analyzed to objectify the occupants' subjective comfort experience. Finally, a report is generated and presents (i) a comparative analysis of the building performance, (ii) a structured and easy-to-understand overview of the current comfort satisfaction as perceived by occupants, (iii) an indication of possible areas of improvement as well as (iv) a suggestion of the measures necessary to raise the comfort level and, eventually, the occupants' satisfaction and productivity.

Keywords: Thermal comfort, visual comfort, acoustic comfort, indoor environmental quality, post-occupancy evaluation

1. Introduction

Indoor environmental quality (IEQ) and comfort some of the primary needs of a working space because it is the place where people spend most of the time after their own homes. Furthermore, according to the UNEP Sustainable Building and Climate Initiative (SBCI), the most of the building stock which will exist in 2050 has been already built (Sbci, 2009). Therefore, with respect to these circumstances, it is important to develop clever solutions aimed at improving comfort and overall occupants' satisfaction of the built environment without neglecting the need to reduce the use of resources and greenhouse-gas emissions. The variety of the office layouts, approaches to HVAC systems, lighting, furnishing and quality management, together create different degrees of the comfort inside a facility. Various studies (such as (Tanabe et al., 2015, Chadburn et al., 2017, Mulville et al., 2016, Haynes, 2008) and others) show that there is a visible correlation between occupants' comfort at the working space and their productivity.

It is reasonable to believe that open offices tend to have more issues with respect to the comfort perception, space management and resource usage due to the variety of employees who share the offices and their perception of the indoor climate.

This paper provides an evaluation of 69 EU office environments based on the data collected from the developed tool for analysis called *Comfortmeter* in the framework of the European Horizon 2020 QUANTUM project.

1.1. Post-occupancy evaluation of the environmental quality in office buildings

Post-occupancy evaluation (POE) was first mentioned in the 1960s. It was introduced as a remedy from significant problems in the field of building performance (Preiser, 1995). The main advantage of POE is that it can help to eliminate health problems, poor air circulation and other issues related to building operation and use. Because, starting from the moment when the building has been built and occupied for some time (Göçer et al., 2015) and ending by demolition, POE delivers an opportunity to track occupants' satisfaction, indoor environment and outcomes from technical maintenance of the building (Khalil and Husin, 2009). All this information is gained via systematically scheduled questionnaire, surveys (such as the Comfortmeter survey), on-site measurements and interviews. The collected information is processed and the results of the evaluation may be used by the facility manager or any other person who is responsible for building operation.

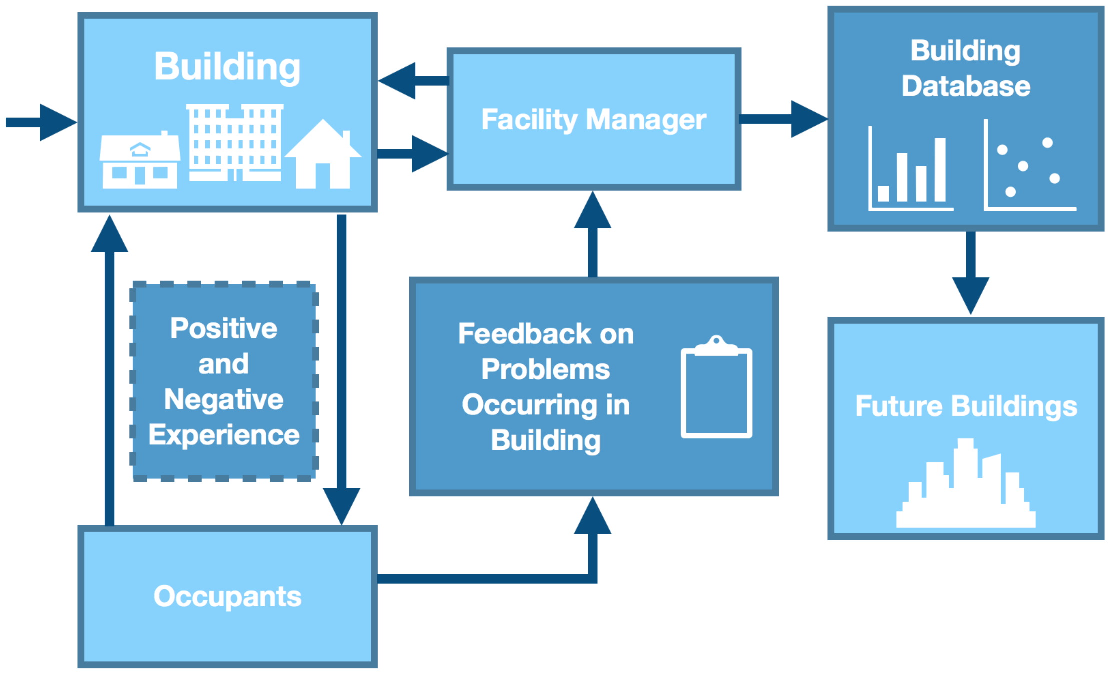

Figure 1 Direct benefits from POE implementation at building facilities

The facility managers (Figure 1) may get a lot of benefits from implementation of POE on a regular basis: feedback from the building occupants provides an opportunity to increase the comfort of the living area (short term benefits), introduction of the feed-forward link between future buildings and operational buildings helps to increase the quality of the future structures (medium term benefit), if occupants' feedback and negative/positive experience are combined in to a database (long term benefit), it may be grounds for future improvements and modeling of building projects (Preiser, 1995). Also, it is possible to use POE results for benchmarking, that in its turn may result in a solid platform for the sustainable development of future construction projects (Göçer et al., 2015).

According to Preiser (1995), POE methodology can be classified into the following approaches: (i) inductive, (ii) investigative, and (iii) diagnostic. In time scale, diagnostic POE is the most time consuming if compared to the other above-mentioned approaches since it may take a month or even years due to high requirements for data accuracy and the wide range of evaluation methods needing to be considered. Inductive POE usually performs fast, as it requires brief data overview and interviews with key persons. Investigative POE is performed in the case when inductive POE has found specific issues which need further investigation. Investigative POE may take up to a few weeks depending on the scale of the building and degree of the problem(s) discovered.

In total, Khalil and Husin (2009) represent schematically a POE application with three sequential phases (Figure 2).

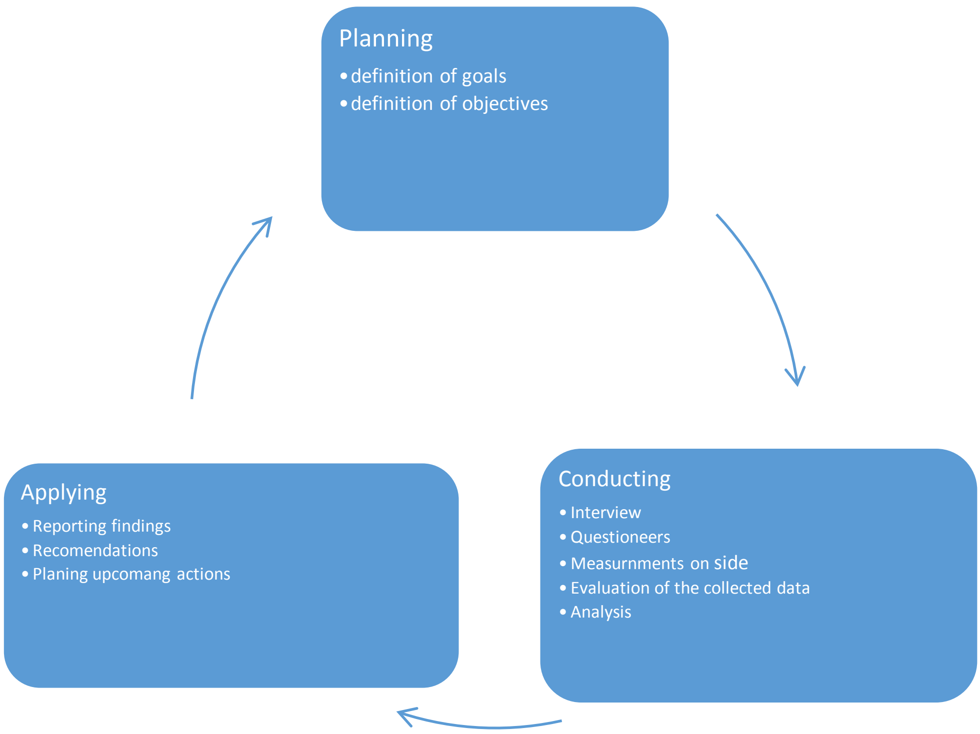

Figure 2 The three phases of the POE cycle

The goal of the POE, and its main objectives and possible outcomes are determined at the planning phase. It is important to determine the main purpose of the investigation (goal), discuss step by step actions and type of the data that should be collected (objectives). Together this is a ground for all investigation and it determines the quality of the achieved results.

The conduction phase associates with data collection. It should be treated carefully with precision and tracking of the inputs from questionnaires, interviews and overall assessment of the building. With this in mind, protected data storage and good architecture of the database are going to provide easy interaction with the information obtained. Since the amount of collected data is usually big, easy to understand acronyms and a logical structure are the keys to straightforward data processing and evaluation without misunderstanding or misinterpretation. This will result in a faster and more precise evaluation process.

The applying phase is the last step in the POE. It includes graphs and tables that present results from the data processing stage. A few options or suggestions for the improvement may be developed based on the outcomes of data processing.

1.2. Measurements of occupants' satisfaction and productivity in offices

The success of any organization is highly dependant on the productivity of its employees. This is an explanation of the variety of studies dedicated to the main components of productivity, and possible approaches and actions to improve it (Clements-Croome, 2006, Al Horr et al., 2016). In general productivity can be defined as the rate of output per unit of input (Al Horr et al., 2016). However, this definition can vary with respect to the industry and company's criteria on productivity calculation (such as management by objectives, quantitative method, measuring sales productivity and many others). That said, comfort at the workplace and satisfaction from the indoor environment are among the key variables which influence employee productivity.

Generally speaking, comfort can be seen as the absence of unpleasant sensations and no trigger to change something in the indoor environment parameters (Hensen and Lamberts, 2012). There are different types of comfort (Figure 3) including physical comfort (e.g., thermal comfort, visual comfort, acoustic, indoor air quality etc.); functional comfort (e.g., distance from work to home, interruptions etc.); psychological comfort (such as privacy, space ownership etc.) (Al Horr et al., 2016).

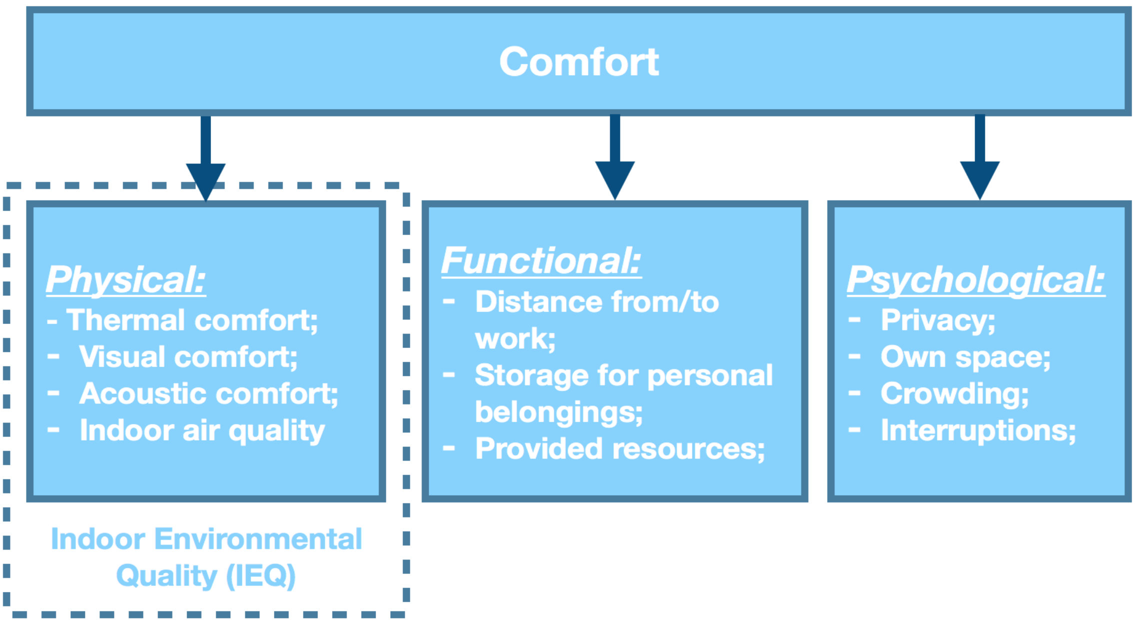

Figure 3 The overview of the main comfort types

Focusing on physical comfort, several methods are available in the literature to assess the performance of a given environment in providing optimal operational conditions for occupants. Several metrics aim at assessing thermal comfort in buildings (Carlucci, 2013, Carlucci and Pagliano, 2012). Furthermore, other metrics may be used to assess a visual environment by evaluating the risk of glare, the amount of light, the light quality of artificial lamps in rendering colors, and the light uniformity (Carlucci et al., 2015). Indeed, elimination of the glare, rational daylight use and illumination are important parameters which need to be well-thought-out during indoor space utilization.

Occupants' perception of the indoor thermal environment is another point to consider. Thermal comfort is assured by the combination of the factors which influence the heat exchange between a person and his/her environment (Croitoru et al., 2015). These factors are predetermined either due to the human body (e.g. age, sex, diet, weight, etc.) or external conditions (e.g. fabrics used for clothes, number of layers, indoor temperature, etc.). Furthermore, thermal comfort may be determined using three different approaches, namely, physiological, psychological and rational (Attia and Hensen, 2014, Enescu, 2017). The physiological approach addresses the thermal perception of humans via the central nervous system and the hypothalamus, where the psychological approach defines thermal comfort, in a general view, as 'a condition of mind that expresses satisfaction with the thermal environment' (Standard, 2004). On the other hand, the rational approach deals with the heat balance of the human body.

Due to the complexity of these phenomena, a number of sensation scales have been developed for the evaluation of personal thermal state (Hensen and Lamberts, 2012). As an example, consider the following scales defined by ISO 10551 (1995): a scale of perception of the personal thermal state, an evaluative scale and a future thermal preference scale (Hensen and Lamberts, 2012, Pagliano and Zangheri, 2010). While the perception scale defines how the person feels at the time he/she is filling out the survey the evaluative scale determines if the actual temperature differs from the comfortable temperature for the person. The future thermal preference scales provide preferences for the future time inside the given space.

On the the other hand, there also exist a set of negative factors, such as high or low air temperature, air speed across body surface, relative humidity, molds, fungi, and etc, that directly impact occupant health, and may result in mucosal, skin irritations, and general symptoms which are temporal and associated with work in particular buildings (Burge, 2004, Crook and Burton, 2010). In the literature, this phenomenon is usually referred to as Sick Building Syndrome (SBS) (Kubba, 2009). Main symptoms of SBS are: nausea, eye irritation, throat irritation, a runny nose, dry skin and so forth (Shan et al., 2016). As a consequence, SBS may result in low productivity among employees, angry behaviour, irritation, depression and often a rise in sick leave(s) (Lim et al., 2015, Beck, 1979). While, symptoms' intensity may vary due to geographical location and climate zones, the approach for SBS detection and tracking remain the same. Among crucial actions in SBS prevention, holding surveys among employees, having regular measurements of indoor conditions, and checking mold formation could be named (Gunnarsson, 2000, Runeson et al., 2006).

1.3. About QUANTUM

The research presented here was developed within the wider research program originated by the European project entitled *Quality management for building performance – Improving energy performance by life cycle quality management* (Quantum) started on 01/01/2016 and ending on 31/12/2019. This research project focuses on the development and demonstration of quality management tools with high replication potentials for building performance in the design, construction, commissioning and operation phases as a means to narrow down the performance gap between predicted and actual energy performance in European buildings.

Furthermore, it is expected that those tools can improve health aspects and user satisfaction while reducing environmental impact.

2. Methodology

A number of scientific studies have shown that the performance capacity and employee satisfaction, enjoyment and health are directly affected by how building occupants perceive the environmental conditions that characterize their working environment. The physical well-being and comfort perception of employees directly impacts their productivity and satisfaction. However, several researchers have shown that, in numerous office environments, indoor environmental conditions are perceived as far from comfortable. Often the main causes are faultily commissioned and operated building management systems, the lack of appropriate and coherent quality management procedures and errors in design or construction of the building systems. In order to identify critical conditions and provide a set of improvement measures, a data collection, and analysis tool has been developed. It is called *Comfortmeter* and is a post-occupancy evaluation tool that is specifically designed for use in office buildings. This tool consists of a survey, a statistical analysis of occupants' responses, and visualization of the analysis outcomes.

The survey does not require an on-site visit nor any software installation on users' computers. It is an online survey accessible with a standard web-browser and is administered via email. Reminders can be enabled to increase the response rate. The online survey investigates the performance of a building through its daily users. It covers comfort-related topics with over 55 questions and documents the performance of the building in respect of thermal, visual and acoustic comfort, indoor air quality, individual control possibilities and the office environment.

After completing the survey, data gathered through the survey undergoes a quality check and then is stored in a database. Next, a user-anonym statistical analysis is carried out on the data stored in the database to objectify the subjective comfort experience of building occupants through an econometric model.

The outcome of the statistical analysis contains detailed and practical advices to create a healthier workplace environment for the building's employees. Specifically, the outcomes are drawn in a report that includes the current satisfaction within the building, the areas of improvement, the measures necessary to for raising the comfort level as well as a quantitative estimation of the impact of the building comfort level score on the employees' productivity. Moreover, a comparison of the analyzed building performance contrasted against the aggregated performance of other and similar previously analyzed office buildings. In summary, the outcomes offer a structured overview of the productivity and comfort satisfaction of the employees working in the building.

3. The statistical analysis and results

Throughout the duration of the task, it was possible to survey 1421 employees with different backgrounds, age and social status. Offices in EU and Scandinavian countries (Figure 4) took part in the Comfortmeter surveys and got feedback on their indoor environment status.

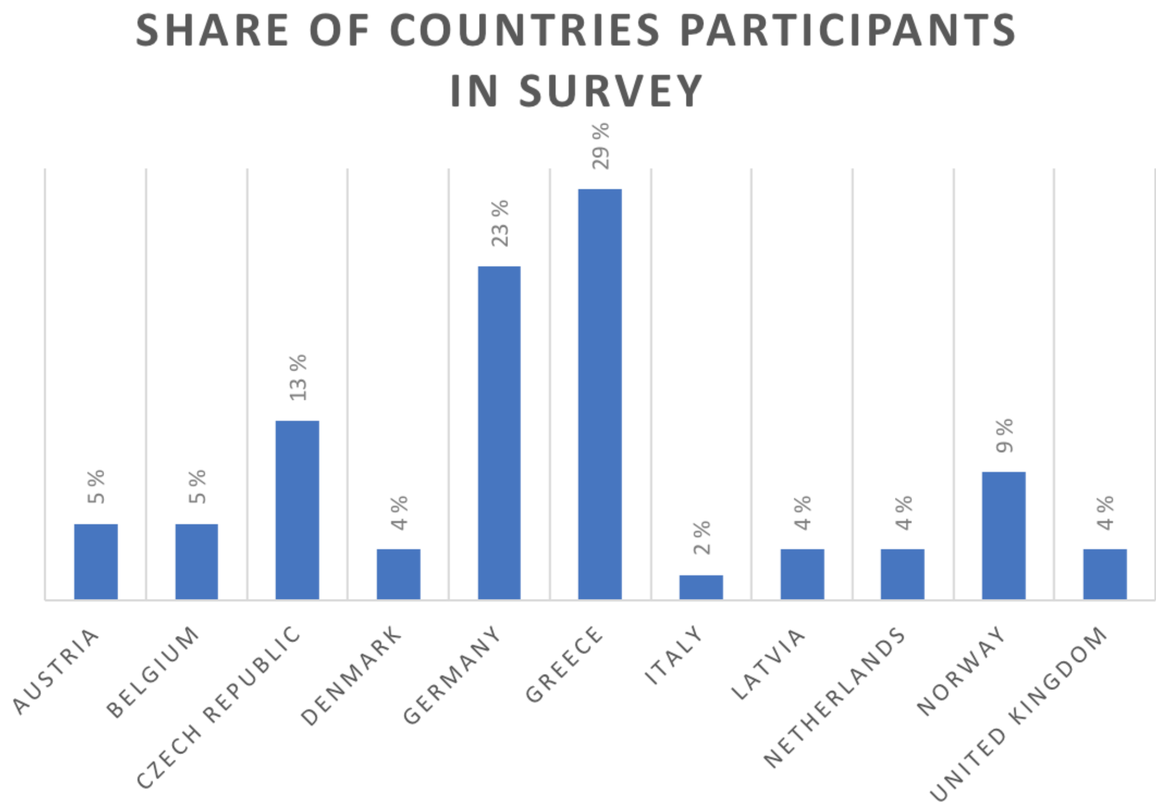

Figure 4 Share of countries participants in survey

Generally, the database has 48% of responses from female and 52% from male employees. This gives a good opportunity to see the difference in perception of the office environment by sex. Data on age is also available and can be seen in Figure 5.

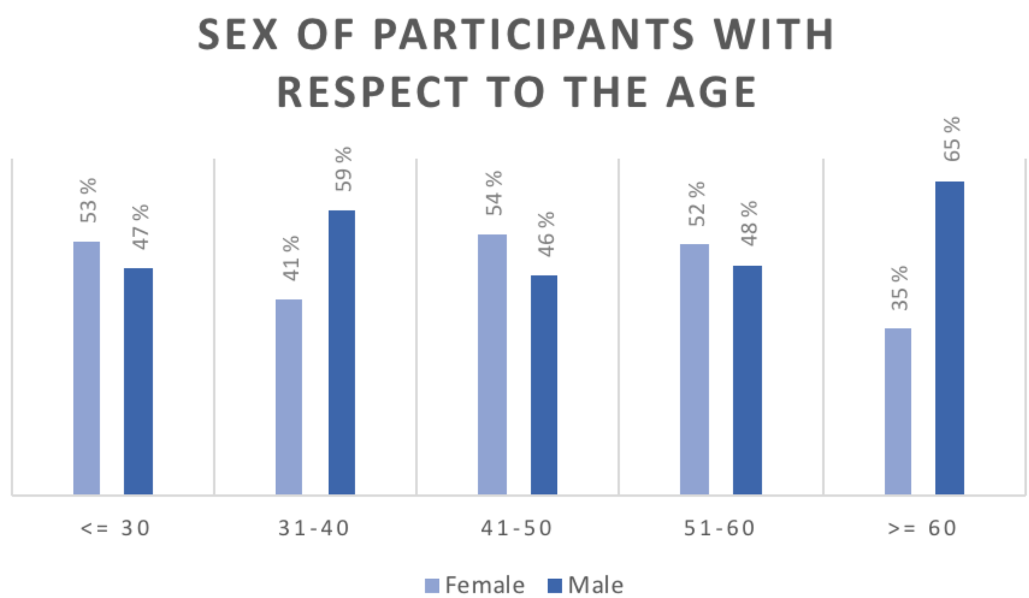

Figure 5 Sex of participants with respect to the age

Since POE is important for the generation of the building profile database, it is important to involve people who have worked in the building for at least the previous 12 months in order to provide a more accurate profile of the indoor environment. Figure 6 presents gathered data on the amount of time employees have been working in the office.

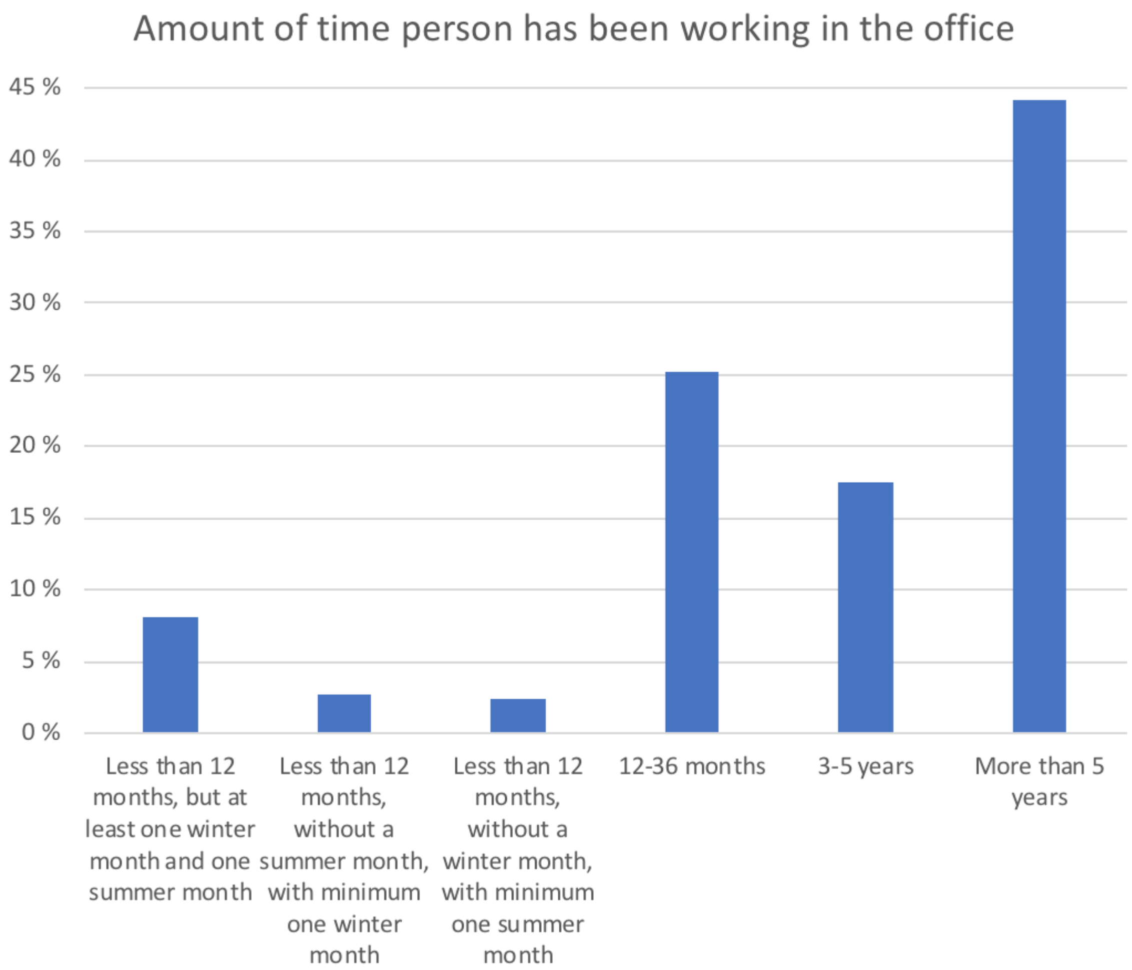

Figure 6 Amount of time person has been working in the office

Since people also have a degree of the responsibility for their indoor comfort, the ability to adapt clothes to the office conditions is another important factor of concern. A detailed overview of the data on ability to adapt clothes to indoor conditions with respect to the gender and age can be observed in Figure 7. But some offices have a specific dress code which will prevent occupants adapting or performing any changes.

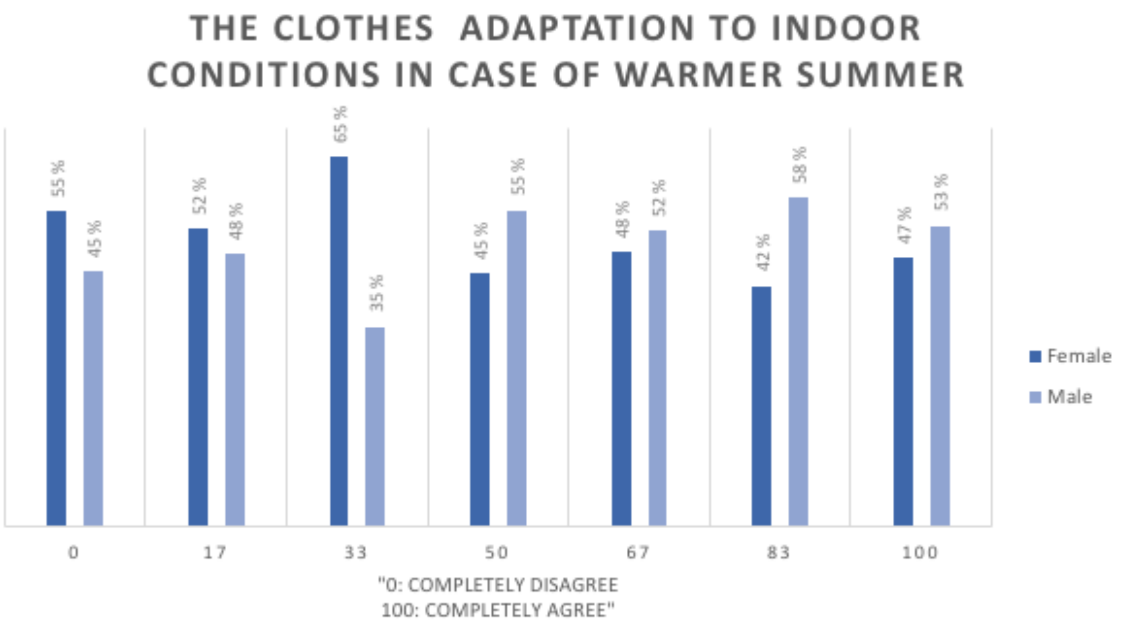

Figure 7 The clothing adaptation in case of warmer summer with respect to the sex and age

Survey data on the degree of the overall satisfaction from the office indoor environment with respect to each individual response showed that the following categories "cleanliness and maintenance of your working space", "amount of light and visual comfort" and "office layout, office furniture, window view etc." have the highest rank of satisfaction among employees.

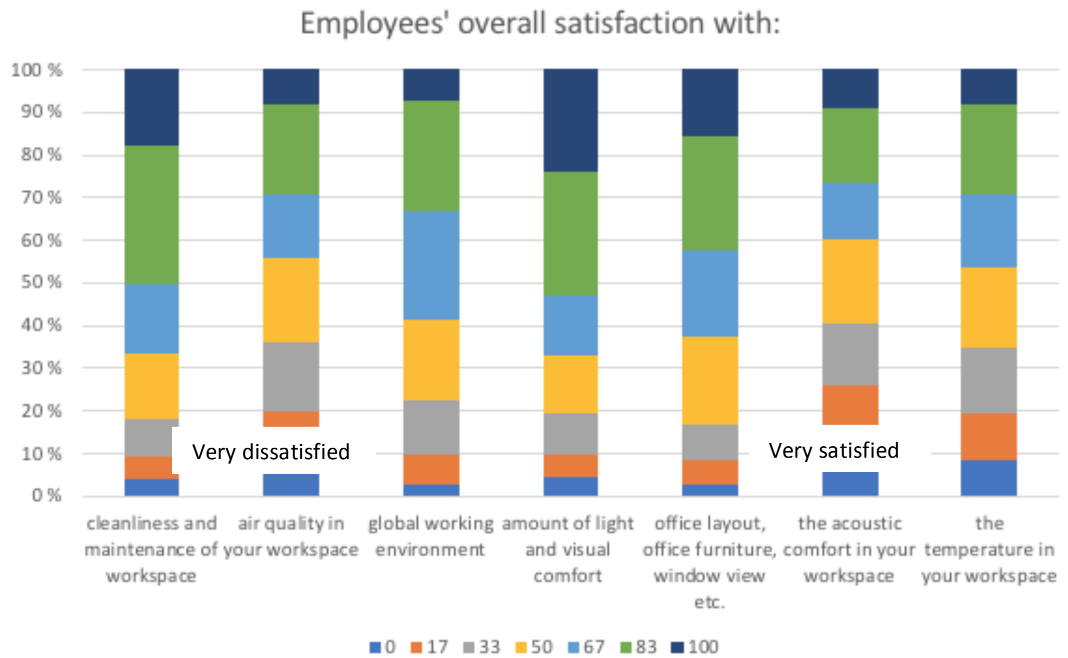

Figure 8 The overall satisfaction from the working space

SPSS statistic software package was used to perform Kruskal-Wallis test in order to analyze variance between independent categorical variable "Age" and number of dependent variables shown at Table 1. The Kruskal-Wallis test reviled a statistically significant difference in indoor satisfaction level across the five different age groups $Gp1: \leq 30, n = 362; Gp2: 31 - 40, n = 405; Gp3: 41 - 50, n = 306; Gp4: 51 - 60, n = 244; Gp5 \geq 60, n = 104$ for the following cases 1, 2, 5, 6, 11, 13, 14, 22 and 23 (see Table 1).

Table 1 Results from the Kruskal-Wallis Test

№	Dependent variables	Age		
		Asymp. Sig.	Age (highest/lowest overall ranking)	
1	The general air quality	0,009	[>= 60]	[<= 30; 31-40; 41-50; 51-60]
2	Clothes adaptation to the warmer conditions	0,011	[31-40; 41-50]	[<= 30; 51-60; >= 60]
3	Overall Satisfaction with cleanness of the office	0,267	[-]	[-]
4	Possibility to regulate the cooling in office	0,547	[-]	[-]
5	Possibility to regulate the heating in office	0,0000209	[31-40; 41-50; 51-60; >= 60]	[<= 30]
6	Possibility to regulate the lighting in office	0,0000139	[31-40; 41-50; >= 60]	[<= 30; 51-60]
7	Overall possibility to regulate environment conditions inside office	0,303	[-]	[-]
8	Overall satisfaction from the working environment	0,529	[-]	[-]
9	Extent to which global working environment affect your productivity	0,709	[-]	[-]
10	Amount of light at workplace	0,384	[-]	[-]
11	The sufficient amount of daylight	0,044	[>= 60]	[<= 30; 31-40; 41-50; 51-60]
12	Overall satisfaction from the amount of light and visual comfort	0,847	[-]	[-]
13	Satisfaction from the office furniture	0,0000525	[41-50; >= 60]	[<= 30; 31-40; 51-60]
14	Office layout	0,004	[41-50; 51-60; >= 60]	[<= 30; 31-40]
15	The overall outdoor appearance of the building	0,451	[-]	[-]
16	Satisfaction from the office layout	0,075	[-]	[-]
17	View from the window	0,387	[-]	[-]
18	In general, my health is good	0,161	[-]	[-]
19	Overall satisfaction from acoustic comfort	0,438	[-]	[-]
20	The sound privacy	0,280	[-]	[-]
21	Overall satisfaction with the temperature	0,059	[-]	[-]
22	In the summer, it is never too warm in my workspace	0,00000207	[>= 60]	[<= 30]
23	In the winter, it is never too warm in my workspace	0,007	[>= 60]	[<= 30; 31-40; 41-50]

(red)	No statistically significant difference
(green)	Statistically significant difference

Case 1 "Satisfaction with general air quality inside the office": the older age group $Gp5 \geq 60$ recorded higher median score (Md = 67) than other groups. $Gp1: \leq 30$, $Gp2: 31 - 40$, $Gp3: 41 - 50$ and $Gp4: 51 - 60$ got lower median score (Md = 50).

Case 2 "Possibility for clothes adaptation to the warmer conditions": $Gp2: 31 - 40$ and $Gp3: 41 - 50$ recorded higher median score (Md = 83) than other groups. $Gp1: \leq 30$, $Gp4: 51 - 60$ and $Gp5 \geq 60$ got the lowest median score (Md = 67).

Case 5 "Possibility to regulate the heating in the office": $Gp2: 31 - 40$, $Gp3: 41 - 50$, $Gp4: 51 - 60$ and $Gp5 \geq 60$ recorded higher median score (Md = 50) than other groups. $Gp1: \leq 30$ got the lowest median score (Md = 33).

Case 6 "Possibility to regulate the lighting in the office": $Gp2: 31 - 40$, $Gp3: 41 - 50$ and $Gp5 \geq 60$ recorded the higher median score (Md = 83). $Gp1: \leq 30$ and $Gp4: 51 - 60$ got the lowest median score (Md = 67).

Case 11 "The sufficient amount of the daylight": $Gp5 \geq 60$ recorded higher median score (Md = 91) than other groups. $Gp1: \leq 30, Gp2: 31-40, Gp3: 41-50$, and $Gp4: 51-60$ got the lowest median score (Md = 83).

Case 13 "Satisfaction form the office furniture": $Gp3: 41-50$ and $Gp5 \geq 60$ recorded higher median score (Md = 83) than other groups. $Gp1: \leq 30$, $Gp2: 31-40$ and $Gp4: 51-60$ got the lowest median score (Md = 67).

Case 14 "Office layout": $Gp3: 41-50$, $Gp4: 51-60$ and $Gp5 \geq 60$ recorded higher median score (Md =83) than other groups. $Gp1: \leq 30$ and $Gp2: 31-40$ got the lowest median score (Md = 67).

Case 22 "In the summer it is never to worm in my workplace": $Gp5 \geq 60$ recorded higher median score (Md =67) than other groups. $Gp1: \leq 30$ got the lowest median score (Md = 41).

Case 23 "In the winter it is never too warm in my workplace": $Gp5 \geq 60$ recorded higher median score (Md =83) than other groups. $Gp1: \leq 30$, $Gp2: 31-40$ and $Gp3: 41-50$ got the lowest median score (Md = 67).

4. Discussion and conclusions

The Comfortmeter is a tool used in the framework of EU project QUANTUM. It has been in operation for a few years already and the creators are working constantly on its improvement in order to deliver knowledge to society. As was highlighted in the previous sections, indoor comfort is a complex term since it is highly dependdent on the age and sex of the person, their background, ethnicity, habits and many more. Given circumstances precede a need for a complex approach in order to improve working environment and as result to increase productivity and satisfaction from the interaction within an indoor space. The Comfortmeter may be used not only to understand a degree of the comfort at the workplace and improve conditions when needed but also for post-occupancy evaluation because it provides an opportunity to create and accumulate knowledge based on previous actions and outcomes.

The survey held in 11 countries provided 1421 responses which are highly beneficial for the future building projects and renovation actions. The gathered database provided insights on such important phenomena as the perception of the comfort of the working environment with respect to the age and gender. Furthermore, the Kruskal-Wallis test revealed statistically significant difference in indoor satisfaction level across the five different age groups Gp1:≤30,n=362; Gp2: 31-40,n=405; Gp3: 41-50,n=306; Gp4:51-60,n=244; Gp5 ≥60,n=104 for the following cases 1, 2, 5, 6, 11, 13, 14, 22 and 23. As result it is possible to conclude that there is a visible connection between age and ability to pursue comfort and adapt to changes.

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