MASTER IN OCCUPATIONAL SAFETY AND HYGIENE ENGINEERING

Dissertation presented in fulfillment of the requirements for the Degree of
Master in Occupational Safety and Hygiene Engineering
Faculty of Engineering of the University of Porto

MODELLIN THE EFFECT OF HUMAN PRESENCE IN AN OFFICE ROOM WITH CFD SIMULATION

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Outubro 2018

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AKNOWLEDGMENTS

To all those who accompanied me during this stage of my life, to the teachers who made this work possible, and to the friends who allowed this period to be much more than that. In a special way:

- To Professor Joana Guedes, for the great honor of having her orientation, taking it as reference of deep knowledge, which is always available to share. I especially appreciate the total willingness to help and all the words of support and motivation, particularly in the most difficult moments.

- To Professor João Baptista, for the availability always provided for clarification of doubts, for the knowledge transmitted and sharing of information.

- To Professor Helena Corvacho, for all the assistance provided for the completion of the work, both for the acquisition of the software license "Design Builder" and for the total and complete availability and transmission of knowledge.

- To the engineer Carlos Melo, for the sympathy, for the acceptance of the elaboration of the dissertation in his company having been a fundamental piece for the accomplishment of this work.

- To Fábio, for the good disposition, for the good moments, for the shared conversations, and especially for the great friendship that will undoubtedly endure.

- To my parents, for the unconditional support they have given me and for the example of parents that they are. For all the sacrifice and effort they have spent to help me become a better human being, by trust and devotion and by being always present.

ABSTRACT

Energy is a precious commodity, with the building sector being one of the most energy consuming worldwide. Therefore, it is crucial to adapt buildings of nowadays for better energy efficiency.

This study was aimed at understanding, exploring and presenting the fundamental principles regarding the influence of human presence in a single office room.

In this sense, theoretical concepts are presented, as well as the methodology inherent to the research process of the theme, which allow a better interpretation and characterization of the final results.

Computational Fluid Dynamics technology is very known worldwide and has been used for the simulation process for time consuming and economic reasons and relatively easy application.

The results of this work show that with small changes it is possible to reduce the energy needs of a building by applying several measures depending on the number of its occupants.

Keywords: CFD simulation, Thermal Comfort, Indoor air quality, Energy efficiency, Thermoregulation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ACE – Air Change Effectiveness

CFD – Computational Fluid Dynamics

CLO - Clothing

DB – Design Builder

LMA – Local Mean Age of Air (s)

M – Metabolic rate (met)

MRT – Mean Radiant Temperature (ºC)

IAQ – Indoor Air Quality

OT – Operative Temperature (ºC)

PMV – Predicted Mean Vote

PPD – Predicted Percentage of Dissatisfied

RH – Relative Humidity (%)

RPH – Renovations per Hour (h^{-1})

TA – Air temperature (ºC)

PART 1

1. INTRODUCTION

1.1 General Introduction

Indoor thermal comfort is one of the most important criteria for a healthy and comfortable building. Thermal discomfort will increase the likelihood of illness and associated symptoms, reduce professional and learning performance, and cause complaints and dissatisfaction regarding the building.

CFD (Computational Fluid Dynamics) has been adopted as a powerful and useful tool for predicting air movement in ventilated spaces, including heat sources and temperature variations. Moreover, it is used routinely in civil engineering when a large demanding ventilation system must be projected.

Energy is a precious resource, with buildings being one of the main sources of energy consumption worldwide. Nevertheless, the construction of buildings has been subjected to a perpetual development over time. As a result, it becomes crucial to adapt nowadays buildings for better energy efficiency.

Nowadays, the building sector requires more than 40% from the total energy consumption in Europe (Eurostat 2016). An automatic question is: How can we reduce this percentage?

Additionally, more than 50% of buildings were built before 1975, which can be translated into a poor energy performance (Brelih et al. 2012, p.3).

In Europe, a more detailed analysis shows that energy consumption can be divided between 68% for residential buildings and 32% for non-residential (Brelih et al. 2012, p.4)

The European Union (EU) has committed itself to a 20% energy saving by the year 2020 (Eurostat, 2016).

The IAQ is an existing parameter critical to workers in office buildings and it is affected by different sources of pollution that are related to the occupants, their activities, but also construction materials, equipment, furniture, heating, ventilation and air conditioning.

Also, the perception of indoor comfort may include several different factors with or without relation among themselves. The Heating, Ventilating, and Air-Conditioning (HVAC) system determines energy and air exchange in buildings

Therefore, it becomes necessary to study this issue as no systematic review on this topic was found in the initial research, regarding the criteria selected in the beginning.

1.2 Legal and Regulatory Framework

ISO 8996: Ergonomics of thermal environment – Determination of metabolic rate (2004) was the document in which metabolic rate of workers was established and ISO 9920: Ergonomics of the thermal environment – Estimation of the thermal insulation and water vapor resistance of a clothing ensemble (2008) provided the clothing insulation values that were crucial to study extreme situations – summer and winter.

ISO 7730 (2005) is a document that closely follows the research developed by P.O. Fanger, with the general principals been adapted by ASHRAE in the norm 55-1981: “Thermal environment conditions for human occupancy”.

ISO 7726: Ergonomics of thermal environment – Instruments for measuring physical quantities (1998) is an international standard that specifies the minimum characteristics of the measuring instruments of the physical variables, as well as it presents methods and procedures of measurement of these parameters. This document helps also to verify the type of study environment by respecting some specific requirements.

Another important standard is ISO 16000-8:2007 which describes the use of single tracer gas for determining the local mean age of air as an indicator of ventilation conditions in a building. This standard is used for the determination of local mean ages of air in buildings for characterizing ventilation conditions.

The described methods are intended for air quality studies and can be used for checking whether the building ventilation requirements are met, estimating the adequacy of ventilation in buildings with indoor air quality problems, and characterizing the strength and distribution of indoor emission sources.

Also, the methods can be applied to all indoor spaces, regardless of the type of ventilation used and the state of mixing of air between zones.

Moreover, ASHRAE Standards 55 for thermal comfort analysis and AHSRAE Standard 62.1 (2013) for ventilation requirements analysis were important working elements of this research.

Finally, the REH («Regulamento do Desempenho Energético dos Edifícios de Habitação») and the RECS («Regulamento do Desempenho Energético dos Edifícios de Comércio e Serviços») were another important regulation documents of this research. As the study-case presents not only commerce and services but mainly it was built for habitation.

2. ARTICLE 1– A SYSTEMATIC REVIEW

Modeling the effect of human presence in a single room with Computational Fluid Dynamics simulation – a systematic review

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ABSTRACT: The purpose of this paper was to contribute with a systematic review to the development of a numerical model that reflects the needs of ventilating a space due to the number of its workers and their working period. The 3D model aim is to consider a better wellness satisfaction and productivity for workers, guaranteeing thermal comfort, optimizing the energetic efficiency of a room for better indoor air quality by addressing the minimum ventilation rates proposed. Through detailed analysis and different researching criteria 24 experimental articles were included and the number of participants ranged between 1 and 22 workers. All articles have a validated model that is significant to study the interaction between human presence in a single room with CFD methodology, which can be hopeful for humans to create a more comfortable, health living environment and to help parametrizing a 3D CFD model in the future.

Keywords: Indoor air quality, CFD simulation, thermoregulation, energy efficiency, thermal comfort.

1. INTRODUCTION

CFD (Computational Fluid Dynamics) has been adopted as a powerful and useful tool for predicting air movement in ventilated spaces, including heat sources and temperature variations. Moreover, it is used routinely in civil engineering when a large demanding ventilation system must be projected.

The construction of buildings has been subjected to a perpetual development over time.

Nowadays, the building sector requires more than 40% from the total energy consumption in Europe (Eurostat 2016), as represented by figure 1. An automatic question is: How can we reduce this percentage?

Additionally, more than 50% of buildings were built before 1975, which can be translated into a poor energetic performance (Brelih et al. 2012, p.3).

In Europe, a more detailed analysis shows that energy can be divided between 68% for residential buildings and 32% for non-residential (Brelih et al. 2012, p.4).

The European Union (EU) has committed itself to a 20% energy saving by the year 2020 (Eurostat 2016).

Conventional indoor air quality (IAQ) ventilation systems are responsible for a significate loss of energy.

The IAQ is an existing parameter critical to workers in office buildings and it is affected by different sources of pollution that are related to the occupants, their activities, but also construction materials, equipment, furniture, heating, ventilation and air conditioning.

Some buildings with low IAQ have the profile case of SBS (Sick Building Syndrome) with the increase of the risk of diseases at the work environment. Thermal discomfort has

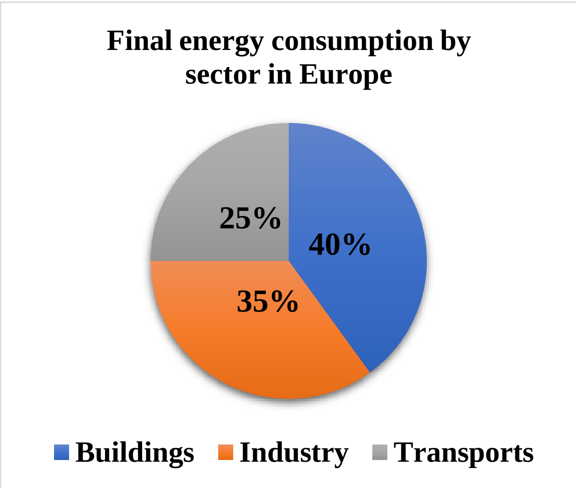

Figure 1: Final energy consumption (Brelih et al. 2012, p.4)

also been known to lead to sick building syndrome symptoms (Myhren & Holmberg 2008).

The combination of high temperature and high relative humidity serves to reduce thermal comfort and indoor air quality (Fang et al. 2004).

On the other hand, a good IAQ helps to provide workers better conditions of hygiene and health, which can improve their daily comfort, satisfaction and productivity.

Temperature influences the performance of tasks in at the office. However, too high or too low temperatures decreases professional work performance. At the office, the ideal temperature range is between 20ºC and 24ºC, with 22ºC being the optimum temperature (Brelih et al. 2012).

The problem that needs to be solved is the air replacement needs (air quality guarantee) and air conditioning due to the occupation and residence time of workers allowing a rationalization of energy resources.

It is crucial to measure the need to ventilate the space, ensuring comfort parameters and legal requirements for occupational health and safety are met.

CFD technique can simulate the needs of ventilation that can help the administrator optimizing the efficiency of an existing ventilated infrastructure and predicting the energetic effectiveness of some equipment, as well as helping to understand what adjustments would be need to be made by changing different boundary conditions.

Fluid flows are governed by partial differential equations which represent conservation laws for the mass, energy and momentum. Therefore, the bases of CFD methodology are the Navier-Stokes equations.

CFD uses algorithms to predict how liquids and gases behave and how they work with the products that people design. By understanding the forces and effects of fluid dynamics it is possible to make critical design decisions that improve efficiency and reduce energy consumption.

Also, this type of analysis allows us to understand the heat transfers inside a room, electronics enclosure, temperature control and airflow management.

2. METHODOLOGY

2.1. *Search strategy*

The survey was conducted due to the academic and clinic PRISMA 2009 Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), through bibliographic database search, which was accessed in January, 2017.

The first aim was to locate all relevant studies. The method to find qualitative studies relied mostly on electronic searches of databases, as well as «Google Scholar». These databases were selected by their relevance in the subject of engineering.

The 7 data bases selected were: *Academic Search Complete*, *American Society of Civil Engineers(ASCE)*, *Scopus*, *Springer*, *Web of Science*, *Inspec* and *Science Direct.*

Literature search strategies were developed considering different types of key-words that can be divided into 5 groups:

- Group A: "CFD Simulation" or "Computational Fluid Dynamics Simulation;
- Group B: "Indoor Air Quality" or "IAQ";
- Group C: "Thermal comfort" or Climatization;
- Group D: Thermoregulation;
- Group E: Efficiency.

In addition to that, 5 combinations were performed between those groups fixing the most important key word that corresponds to group A. The combinations were the following:

- A & B & C;
- A & B & D;
- A & B & E;
- A & C & D;
- A & C & E,

The previous combinations consisted on searching only abstract, title and keywords in the field camp, extinguishing some database where that search field was not available, so it was considered the camp «full text» (ASCE, Springer and Academic Search Complete).

Another type of combinations would not have been possible to perform since the output was null every time, as it occurred with the data base from *IEEE Xplore*.

In this systematic review, the final studies were selected per 8 criteria, 4 of exclusion and 4 inclusion, which were chosen to provide a good quality, decision-making and goal-oriented survey/research.

Articles obtained by this systematic search were exported to *Mendeley*'s reference manager and then organized by types of combinations in different directories.

2.2. *Screening and exclusion criteria*

In the initial research, all articles resulting of the 5 combinations mentioned above related with the topic were screened for title, abstract and keywords.

After that, exclusion criteria were applied. These criteria were simple as limiting the systematic research by a period of 10 years, ranging from January 2007 until January 2017.

Moreover, all studies were filtered by the English as it is the universal language and for practical reasons.

Another exclusion criterion was the limited type of documents that were included in the analysis: articles, reviews, articles in press and journals.

Lastly, there was the exclusion criteria of our database documents not having the "full text" available or simply not having access to the entire document.

2.3. *Inclusion and eligibility criteria*

Considering the initial research, the studies which possessed mathematical models of ventilation systems, indoor air quality and thermoregulation were included.

In addition, another inclusion criteria consisted on the actual validation of those models which symbolizes the high level of trust in the researched models.

Another criterion was the sub-domain of the studies which focus only on the indoor space of simulation (bedrooms, office rooms and climate chambers).

The final inclusion criterion, was made by including the human factor, by a wide range of approximations that considered thermal manikins, virtual manikins, and simple objects as heat sources. This last criterion traduces the study of the influence of human presence in the indoor environment which is one of the main goals of the present research.

The final selected papers included every single criterion mentioned above simultaneously experimentally validated and with the content required by all the criteria.

Only articles that were free for downloading by using the University of Porto federate credentials were included.

To sum up, this was the best strategy of research defined to this systematic review.

3. RESULTS

The database search process yielded a total of 735 papers, before duplicates removal.

After removing duplicates (n=250) and excluding the non-relevant papers (n=183), 67 full-text articles were analyzed, with 19 meeting criteria for inclusion.

Consequently, a full iteration of the references and bibliography of those 19 articles was made by a new cycle of documents, resulting in an addition of 31 extra articles to the research.

The new cycle of papers was again screened, considering the free-date criteria.

Finally, eligibility criteria were applied, considering only articles that met all criteria described in *2.3* simultaneously.

From the total papers obtained initially, only 24 met the qualitive selection criteria at the end by the proceeding outlined in figure 2.

In table 1, all articles were analyzed by some relevant topics with their main characteristics represented.

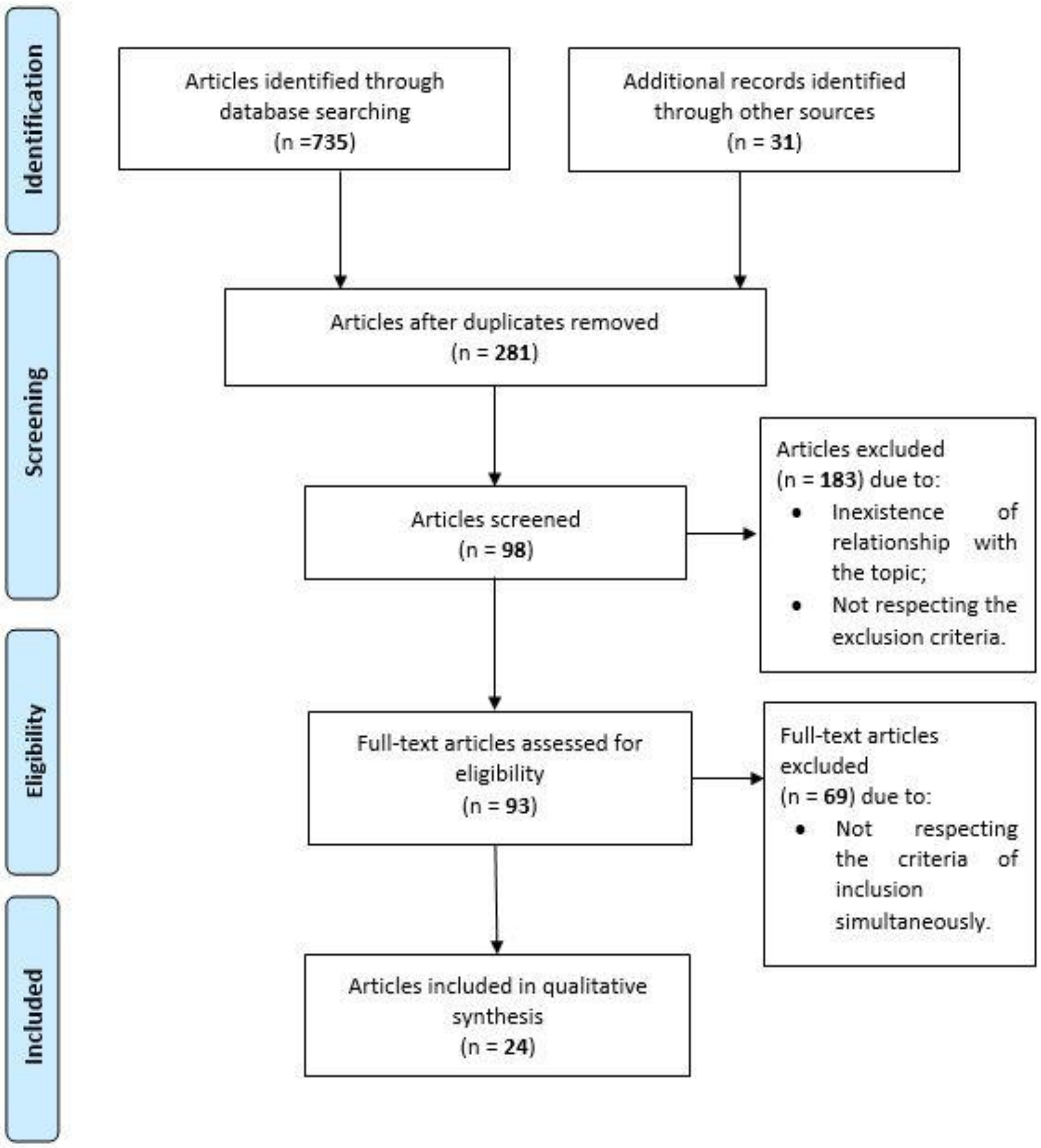

Figure 2: Diagram of the selection of articles.

Table 1: Summary of main data and characteristics of all studies.

Author and year	*Location of the study*	*Phenotype of the sample and type of work evaluated*	*Indoor space of simulation*	*Study description Approach techniques*	*Equipment used for measurement*	*Another heat sources included*
(Gao et al. 2007)	China	1 breathing thermal manikin with an artificial lung was evaluated with the sitting posture	Office room (4,00 x 3,00 x 2,70 m)	• 3D air flow CFD simulation with multi-nodal human-thermoregulation model; • 19 cases of simulation for the investigation of the inhaled air quality (DV and PV systems)	Experimental air-conditioning data used to validate	1 vertical heat source (300W) and a computer (120W)
(He et al. 2011)	Hong Kong (China)	2 manikins with seated height of 1.30 m and 1.40 m Seated	Office room (4,80 x 5,40 x 2,60 m)	• 3 different total volume strategies: DV (displacement ventilation), UFAD (under-floor air distribution) and PV (personalized ventilation)	Velocity and temperature sensors	2 monitors (198 W each) and 2 lamps (18 W e.)
(Huang & Tuan 2010)	China	1 sedentary occupant (M=1.0) in the room; Type of work evaluated: Seated position	Working room (10,00 x 5,00 x 3,20 m)	• New concept in energy-saving equipment (RACM); • Regional air-conditioning mechanism: Comparing 2D to 3D CFD model by 9 types of simulation.	Flow meter sensor; Temperature sensor.	None
(Voelker et al. 2014)	Germany	1 thermal manikin with seated height of 1.35m nicknamed “Feelix”; Evaluation of the sitting posture	Climate chamber (3,00 x 3,00 x 2,44 m)	• Different techniques (Particle Streak Tracking, thermography, anemometry, and thermistors); • UC Berkeley thermoregulation model	Air velocity sensors (Anemometers); 20 thermistors (NTC) and a camera	None
(Bolineni et al. 2015)	Germany	1 manikin of 1.80 m tall and sitting height of 1.35 m; Evaluation of standing and sitting posture	Displacement ventilated room (3,60 x 3,60 x 3,00 m)	• Presentation of a developed reduced order model where DV flow regimes are detailed; • «Fanger» and «Fiala» heat balance equations; • 240 cases simulated in sub-domain (GUI software)	Velocity and temperature sensors	None
(Zhuang et al. 2014)	China	Sedentary human model with 1,15 m of nose height Type of work evaluated: Seated	Office room (4,00 x 3,20 x 2,80 m)	• How to improve ventilation effectiveness; • Application into twelve typical office situations/cases under different ventilation schemes	Cylindrical momentum source	1 computer (130W) and lights (80W)
(Yan et al. 2016)	Australia	Thermal manikin model (Licina et al. 2014) 1.68 m tall and 1.23m of sitting posture; Type of work evaluated: Seated	Climate chamber (4,00 x 3,00 x 2,60 m)	• CFX 14,5 (Ansys) using the RNG k- turbulence model and SIMPLEC algorithm applied; • 3D scanned CSP (Computer simulated person) with «Nilsson» model.	Experimental data used to validate	None
(Conceição et al. 2010)	Portugal	1 manikin with 1.70m of height and 70 kg Type of work evaluated: Seated	Wood experimental chamber (2,70 x 2,40 x 2,40 m)	• Multi-nodal human thermal comfort model • SIMPLE and TDMA (Tri-Diagonal Matrix) algorithms	Multi-data logger; MICKROMEK sensors; LSI sensors	None
(Conceição et al. 2013)	Portugal	2 manikins (1,70m tall and 70kg) Type of work evaluated: Seated	Chamber (2,70 x 2,40 x 2,40 m)	• Multi-nodal human thermal comfort numerical model • SIMPLE and TDMA (Tri-Diagonal Matrix) algorithms	Multi-data logger MICKROMEK sensors; LSI sensors	None

Table 1: Summary of main data and characteristics of all studies (cont.).

Author and year	*Location of the study*	*Phenotype of the sample and type of work evaluated*	*Indoor space of simulation*	*Study description/ Approach techniques*	*Equipment used for measurement*	*Another heat sources included*
(El-Fil et al. 2016)	Lebanon	1 thermal manikin; Type of work evaluated: Seated and completing tasks at the PC.	Climate chamber (3,40 x 3,40 x 2,80 m)	• ANSYS Fluent with bio-heat model validated integrated with 3D CFD model; • Energy analysis calculations to better efficiency and savings.	CO_2 concentration sensors	1 desktop computer (93 W)
(Kobayashi & Tanabe 2013)	Japan	Case 1: 6 male subjects (21-27 years, weight: 74.2 kg, height: 1.80 m); Case 2: 4 male subjects (23-25 years, height: 1.75 m; weight: 66.5 kg); Standing and sitting posture	Climate chamber without ventilation	• Human thermoregulation model called JOS-2 • Stable conditions evaluated (Case1) and compared with nonuniform and transient conditions (Case 2)	Control system with sensor signal and integrated signal	None
(Wang & Tian 2013)	China	4 seated dummies acting as human beings; Seated posture evaluated	Test chamber (4,50 x 4,50 x 3,00 m)	• Taguchi Method was used to choose from the optimal air supply and to analyze thermal comfort by different factors; • Airpak simulation tool with ADPI and PMV; Comparison of DOAS.	Probes of temperature and air velocity	4 heat sources (180 W each)
(Zhai & Metzger 2012)	USA	2 occupants (1.70m tall average women); Type of work evaluated: Seated and completing cognitive tasks at the PC	Typical office environment with two workstations (5,40 x 4,80 x 2,60 m)	• Taguchi Method with PV (Personalized Ventilation) systems for predicting IAQ, PMV and energy efficiency; • Comparison to a system mixing ventilation	Sensors mounted in the mouth of each manikin to measure the inhaled air temperature	2 computer monitor, 2 computer tower, 2 desk lamps
(Kanaan et al. 2012)	Lebanon	1 thermal manikin with seated height of 1.20 m and a surface area of 1,78m^2; Seated and completing tasks at the PC	Climatic chamber (2,50 x 2,75 x 2,80 m)	• 3D CFD simulation using published experimental data and commercial software Airpak comparing the results with CO_2 concentrations	CO_2 concentration sensors;	Wall plume
(Makhoul et al. 2015)	Lebanon	1 thermal manikin with seated height of 1,20 m and a surface area of 1.78m^2 Type of work evaluated: Seated	Typical office chamber (3,40 x 3,40 x 2,60 m)	• The effect of the jet flow rate, temperature and inclination angle on air quality at the breathing zone of the occupant was investigated with the coaxial personalized ventilation; Gagge's model.	CO_2 sensors; 9 T-type thermocouples with 9 ± 0.3ºC accuracy	Heated vertical cylinder
(Makhoul et al. 2013)	Lebanon	1 thermal manikin with seated height of 1,20 m and a surface area of 1.78m^2 Type of work evaluated: Seated	Typical office chamber (3,40 x 3,40 x 2,60 m)	• Single jet ceiling-mounted PV nozzle in the conditioned space; • Integration with a bioheat validated Gagge's model for thermal sensation.	CO_2 sensors («Alphasense») Electric heaters	Heated cylinder source

Table 1: Summary of main data and characteristics of all studies (cont.).

Author and year	*Location of the study*	*Phenotype of the sample and type of work evaluated*	*Indoor space of simulation*	*Study description Approach techniques*	*Equipment used for measurement*	*Another heat sources included*
(Sevilgen & Kilic 2011)	Turkey	Manikin (1,70 m tall with 70 kg and total surface are of 1,81m^2) Type of work evaluated: Seated	Typical office room (4,00 x 4,00 x 3,00 m)	• Energy consumption approach; • 3 Dimensional steady-state numerical analysis.	Velocity, HR and temperature sensors	None
(Lee et al. 2009)	USA	2 ,4 and 6 subjects in different types of simulation; Evaluation of standing (1,70 m) and sitting posture (1,10 m)	Chamber with a window (4,80 x 4,20 x 2,73 m) Office room, classroom and workshop	• Study of UFAD and TDV systems with 7 cases of simulation; • Comparison between the types of ventilation showing its efficiency with a validated model and simple algorithm.	Velocity, HR and temperature sensors	Different equipment used (200W- 400W) Heated boxes
(Yang et al. 2014)	China	1 woman and 1 man; Evaluation of standing and sitting posture.	Bedroom (3,90 x 2,80 x 3,30 m)	• CFD simulations with variation of indoor conditions; • Wall-hang air conditioning analyzed.	CO_2 concentration sensors	TV set (300W); Cylinder (550W); Lamp (550W).
(Cheng & Lin 2015)	Hong Kong (China)	28 Female Subjects (19.8 ± 1.4 years, 53.2 ± 8.2 kg, 1.61 ± 0.05 m); 19 Male Subjects with 20.1 ± 1.2 years, 65.7 ± 10.8 kg, 1.72 ± 0.04m; Seated position	Environmental chamber (8,80 x 6,10 x 2,40 m)	• CFD simulation by EDTS (effective draft temperature for stratum ventilation); • PMV (predicted mean vote) and PPD (predicted percentage dissatisfied) and PD (percentage dissatisfied due to draft)	Central monitoring station	Lamps (21 X 56 W) and computers (2 x 150 W)
(Park & Chang 2014)	Korea	2 occupants: One seated and another standing up Standing and sitting	Typical office room (6,65 x 4,01 x 2,70 m)	• Simulation of various combinations of ceiling and floor-based air distribution systems; • Numerical model to optimize the level of thermal comfort and IAQ.	Sensors for air temperature, velocity and CO_2 concentrations	Thermal plumes
(Kong et al. 2015)	USA	Manikin with seated height of 1,35m; Evaluation of sitting posture.	Office room (6,25 x 10,52 x 3,15 m)	• STAR-CCM to compare the simulation made with the experimental results; • Brief evaluation of environmental quality for PV and UFAD.	CO_2 sensors	1 Computer processor and 1 monitor
(Balocco et al. 2014)	Italy	Human occupants; Evaluation of moving people Standing posture evaluated	Historical building: The «Derossiana Room»	• Indirect approach to the numerical simulation of movements in a fluid combined with heat, moisture and multi-physical conditions. • CFD-FEM to predict humidity, air temperature and movement over time; Transient conditions.	1 Microclimatic station with a thermo-camera “Flyr”) and a radio master RLog data logger	Lamps
(Loomans et al. 2008)	The Netherlands	11 occupants (Operating team of 8 people + 1 surgeon + 1 anesthetist + 1 patient) Standing posture evaluated	Operating theatre (6,00 x 7,70 x 3,10 m)	• CFD-code named WISH3D validated by several international research projects to assess the performance of the ventilation system	Tracer gas equipment measurement	Personal equipment (400W) and lamp (200W)

4. DISCUSSION

Different types of indoor spaces have been evaluated such as office rooms, climatic chambers, bedrooms and operating rooms.

About 67% (16 articles) of the selected studies had another type of heat sources included in the experimental campaign and the remaining 33% (8 articles) had zero heat sources included.

The sample of the studies, consisted in 83% of thermal manikins and 17% of real human occupants. Considering now the type of work evaluated, about 67% (16 articles) considered only the seated position, while approximately 8% (2 articles) considered the standing posture and the remaining 25% (6 articles) studied both positions.

According to Portuguese law ("Portaria nº987/93") which is based on the European Framework Directive 89/654/EEC of 30 November 1989, concerning the minimum safety and health requirements for the workplace the minimum volume per worker is established at 11,50 m^3 (10,50 m^3 in cases where is secured to have a good ventilation).

Analyzing all work selected, calculations were made which lead to approximately 18% with a rate of volume per worker until 11,50 m^3, 27% with a rate between 11.50 and 23,0 m^3 and the remaining 55% with an excessive rate of more than 23 m^3 per person.

Also, from the 24 articles obtained, approximately 90% (22 papers) have their experience validated under steady-state conditions which has relevance in the thermodynamics field.

The remaining 10% (2 papers) have their experimental study validated under transient and non-uniform conditions.

A presumed limitation to this survey includes the search process itself, due to the exclusion of good documents simply because they didn't respect all the criteria simultaneously but were exceptionally developed at some topics which were relevant to the present work.

Consequently, this may not have allowed the identification of all studies related to this research field, leading the results to more accurate and concrete cases of analysis.

From the studies which investigated ventilation systems, thermal comfort and thermoregulation some important conclusions and citations are mentioned:

"The higher the temperature difference between the surface temperature of the manikin and the air temperature, the faster the airflow in the microclimate" (Voelker et al. 2014).

An automatic question to the previous statement is: in summer conditions, when there is a need of maximize ventilation, the temperature differential should be higher but that occurs in winter so it's a paradox issue.

"Stratum ventilation can be applied in a room with a multiple row of occupants" (Cheng & Lin 2015).

"The RACM (Regional-air-conditioning) produces an airflow circulation cell for satisfying the thermal comfort demands for users, and can potentially be energy-saving" (Huang & Tuan 2010).

"Displacement ventilation (DV) provides better inhaled air quality than mixing ventilation (MV) except in the situation where contaminants are emitted from the floor"(Gao et al. 2007).

"DV is more energy efficient than MV since it is only aimed at conditioning the occupied zone" (Gao et al. 2007).

"Using better insulation and a low-temperature panel radiator is more effective with regard to thermal comfort and energy savings"(Sevilgen & Kilic 2011).

"Intensity of fatigue, headache and difficulty in thinking clearly decreased when subjects worked at slightly lower levels of air temperature and humidity"(Fang et al. 2004).

"The TDV and UFAD systems had better ventilation performance than the mixing ventilation (MV) system in cooling mode. For heating mode, the TDV and UFAD system created mixing conditions except in the vicinity of the floor" (Lee et al. 2009).

"The desk-mounted fans were able to reduce the convection plumes around the occupant and improved the performance of the single jet PV nozzle by doubling the ventilation effectiveness and improving comfort. They permitted also to achieve a reduced energy saving by up to 13% when compared with conventional mixing ventilation systems" (Makhoul et al. 2013).

"The results have indicated that having both ceiling and floor-based air conditioning systems would allow the flexibility to change supply and exhaust air diffuser locations to optimize thermal and ventilation performance more efficiently in countries that are subject to distinct seasonal changes" (Park & Chang 2014).

"The proposed coaxial personalized ventilation achieved high air quality in the breathing zone demonstrated by a personal exposure effectiveness of 32% at fresh airflow rate of 0,01 $m^3.s^{-1}$ per person. It contributed also to the attainment of temperature differences up to 2ºC between the occupant's microenvironment and the rest of the room air leading to consider- able energy savings compared to the mixed convection air conditioning" (Makhoul et al. 2015).

"When operating the chair fans, the ventilation effectiveness (23,39%) increased by almost 2,5 times that when chair fans were turned off (9,31%). The fan height and fan flowrate have a dual effect on the thermal comfort and IAQ, where the best IAQ is achieved at different fan configuration than that of thermal comfort. Therefore, optimal height and flow rate are selected to help maintain the best combination of IAQ and thermal comfort. A peak in energy savings is achieved at the best IAQ case (fan height 50 cm - 19,69 in.) and a total flow rate 10 L/s [0,35 ft^3/s]) reaching 17% when compared with mixing ventilation" (El-Fil et al. 2016).

"There are several models that can predict human physiological response to heat and cold environment. However, there are only a few models that simulate and predict the temperature distribution all over the body, considering the individual differences and transient conditions" (Guedes et al. 2014).

The main goal was to present a systematic review on the studies that can conduce to a final 3D model capable of predicting the needs of ventilation of a space due to the presence of human beings. This model should maximize its energetic efficiency and satisfaction to workers.

5. CONCLUSION

In the present research, the results showed a wide range of documents due to the wide range of the study, but only 24 papers were included to represent the criteria selected in this systematic search.

All articles respected simultaneously the 8 criteria (date, type of document, "full-text" availability, language, mathematical models, experimental part, proper validation and indoor space domain) initially established in consequence of the different 5 types of combinations.

Although several studies examined the significance of thermoregulation models and its correlation with the indoor environment as well as ventilation systems, which are crucial to investigate the internal comfort conditions by the CFD technique, no systematic review was founded to be produced so far considering this topic.

Nevertheless, a wide range of articles that studied different types of ventilation systems were found which is positive considering its impact on the investigation of internal comfort conditions.

Therefore, this systematic review was a novelty that considered the models as essential but also their empirical validation.

To sum up, the results provided a good panoply of papers of high confidence to help on the development of the 3D CFD model in the future project by respecting all the criteria simultaneously.

6. REFERENCES

Balocco, C., Petrone, G. & Cammarata, G., 2014. Numerical multi-physical approach for the assessment of coupled heat and moisture transfer combined with people movements in historical buildings. *Building Simulation*, 7(3), pp.289–303.

Bolineni, S., Stratbücker, S. & van Treeck, C., 2015. Development of reduced order flow responsive models of convective heat transfer for human body segments. *Building Simulation*, 8(4), pp.393–404.

Brelih, N. et al., 2012. *Design of energy efficient ventilation and air-conditioning systems*, Brussles: REHVA: Federation of European Heating and Air-conditioning Associations.

Cheng, Y.. & Lin, Z.., 2015. Technical feasibility of a stratum-ventilated room for multiple rows of occupants. *Building and Environment*, 94, pp.580–592.

Conceição, E.Z.E. et al., 2010. Evaluation of comfort level in desks equipped with two personalized ventilation systems in slightly warm environments. *Building and Environment*, 45(3), pp.601–609.

Conceição, E.Z.E., Lúcio, M.M.J.R. & Awbi, H.B., 2013. Comfort and airflow evaluation in spaces equipped with mixing ventilation and cold radiant floor. *Building Simulation*, 6(1), pp.51–67.

El-Fil, B., Ghaddar, N. & Ghali, K., 2016. Optimizing performance of ceiling-mounted personalized ventilation system assisted by chair fans: Assessment of thermal comfort and indoor air quality. *Science and Technology for the Built Environment*, 22(4), pp.412–430.

Eurostat, 2016. Buildings - Energy Efficiency. Available at: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings [Accessed January 13, 2017].

Fang, L. et al., 2004. Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance. *Indoor Air*, 14(7), pp.74–81.

Gao, N.P., Zhang, H. & Niu, J.L., 2007. Investigating indoor air quality and thermal comfort using a numerical thermal manikin. *Indoor and Built Environment*, 16(1), pp.7–17.

Guedes, J.C., Santos Baptista, J. & de Carvalho, J.M., 2014. 3D human thermoregulation model: Bioheat transfer in tissues and small vessels. In G. Arezes, PM and Baptista, JS and Barroso, MP and Carneiro, P and Cordeiro, P and Costa, N and Melo, RB and Miguel, AS and Perestrelo, ed. *Occupational Safety and Hygiene II*. Guimarães: Taylor & Francis, pp. 669–673.

He, Q. et al., 2011. CFD study of exhaled droplet transmission between occupants under different ventilation strategies in a typical office room. *Building and Environment*, 46(2), pp.397–408.

Huang, K.D. & Tuan, N.A., 2010. Numerical analysis of an air-conditioning energy-saving mechanism. *Building Simulation*, 3(1), pp.63–73.

Kanaan, M., Ghaddar, N. & Ghali, K., 2012. Quality of inhaled air in displacement ventilation systems assisted by personalized ventilation. *HVAC&R Research*, 18(3), pp.500–514.

Kobayashi, Y. & Tanabe, S., 2013. Development of JOS-2 human thermoregulation model with detailed vascular system. *Building and Environment*, 66, pp.1–10.

Kong, M., Zhang, J. & Wang, J., 2015. Air and air contaminant flows in office cubicles with and without personal ventilation: A CFD modeling and simulation study. *Building Simulation*, 8(4), pp.381–392.

Lee, K. et al., 2009. Comparison of Airflow and Contaminant Distributions in Rooms with Traditional Displacement Ventilation and Under-Floor Air Distribution Systems. *ASHRAE Transactions*, 115(2), pp.306–321.

Loomans, M.G.L.C.. d et al., 2008. Performance assessment of an operating theatre design using CFD simulation and tracer gas measurements. *Indoor and Built Environment*, 17(4), pp.299–312.

Makhoul, A., Ghali, K. & Ghaddar, N., 2013. Desk fans for the control of the convection flow around occupants using ceiling mounted personalized ventilation. *Building and Environment*, 59, pp.336–348.

Makhoul, A., Ghali, K. & Ghaddar, N., 2015. Low-mixing coaxial nozzle for effective personalized ventilation. *Indoor and Built Environment*, 24(2), pp.225–243.

Myhren, J.A. & Holmberg, S., 2008. Flow patterns and thermal comfort in a room with panel, floor and wall heating. *Energy and Buildings*, 40(4), pp.524–536.

Park, D.Y. & Chang, S., 2014. Numerical analysis to determine the performance of combined variable ceiling and floor-based air distribution systems in an office room. *Indoor and Built Environment*, 23(7), pp.971–987.

Sevilgen, G. & Kilic, M., 2011. Numerical analysis of air flow, heat transfer, moisture transport and thermal comfort in a room heated by two-panel radiators. *Energy and Buildings*, 43(1), pp.137–146.

Voelker, C., Maempel, S. & Kornadt, O., 2014. Measuring the human body’s microclimate using a thermal manikin. *Indoor Air*, 24(6), pp.567–579.

Wang, W. & Tian, Z., 2013. Indoor thermal comfort research on the hybrid system of radiant cooling and dedicated outdoor air system. *Frontiers in Energy*, 7(2), pp.155–160.

Yan, Y., Li, X. & Tu, J., 2016. Numerical investigations of the effects of manikin simplifications on the thermal flow field in indoor spaces. *Building Simulation*.

Yang, L., Ye, M. & He, B.-J., 2014. CFD simulation research on residential indoor air quality. *Science of the Total Environment*, 472, pp.1137–1144.

Zhai, Z. (John) & Metzger, I.D., 2012. Taguchi-Method-Based CFD Study and Optimisation of Personalised Ventilation Systems. *Indoor and Built Environment*, 21(5), pp.690–702.

Zhuang, R., Li, X. & Tu, J., 2014. CFD study of the effects of furniture layout on indoor air quality under typical office ventilation schemes. *Building Simulation*, 7(3), pp.263–275.

PART 2

3. DEFINITION OF OBJECTIVES AND METHODOLOGY

3.1 Background

Since people spend 80 to 90% of their time inside buildings, it becomes crucial studying the most efficient way of building ventilation. The growing concern about energy efficiency of buildings makes their thermal performance improvement a very current concern.

Therefore, meeting the minimum requirements of comfort and maintaining a good indoor air quality are important topics of discussion. The occupants are expected to be the key factor affecting the thermal airflow patterns in built indoor spaces. This work intends to study the influence of human presence in a singular room and to design different solutions for its energy efficiency. One of the most widespread strategies to achieve this is improving ventilation efficiency.

Base on the previous scenario, it was tried to understand and to base the methods of numerical simulation that allow to characterize and calculate as accurately as possible the dynamic behavior of the interior of a space.

In order to do that, it is presented a thermal comfort assessment study with the conditions of a services and housing building comparing values with the applicable standards.

3.2 Objectives and methodology

For the purposes mentioned above, a numerical analysis was performed through dynamic simulation using the Design Builder software, from which it is expected to obtain values of energy needs, internal thermal gains, PMV and PPD indexes and other parameters to evaluate thermal performance.

Initially the study case was selected (office room) and it was made a brief description of its internal conditions: number of occupants, physical traits, number of hours of working period, types of materials and their properties, as well as external surroundings: localization and orientation.

The object of study of this dissertation is an office room of a building built in the 90’s, for which it was proposed to analyse the thermal comfort in function of its occupancy and before and after the changes.

Some specific measures were taken in the field with the goal of knowing the real dimensions and volume the office-room.

The superior and inferior levels were also parametrized and the simulations were then performed comparing different scenarios.

To perform the internal evaluation of the office a software was used for practical reasons of time consuming and expensive measurement equipment.

Also, some specific objectives were a thermal comfort study, a characterization of the type of environment simulated over time in different periods (summer and winter, which are opposite heat sensation situations), the verification by standards if the environment was homogenous or not and transient or steady-state, the verification of the air change rate in relation with IAQ (indoor air quality), the analysis of air speed inside the office-room, the assessment of the PMV and PPD indexes for the periods in which it is likely to be applied, checking the local thermal discomfort caused by vertical air temperature differences, draft, radiant asymmetries during periods of occupation.

Modelling the effect of human presence in a single room with Computational Fluid Dynamics simulation

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ABSTRACT: The purpose of this paper was the study and analysis of the performance characteristics of an office room by using a numerical model that reflects the needs of ventilating a space due to the number of its workers and their working period. The 3D model aim is to consider a better wellness satisfaction and productivity for workers, guaranteeing thermal comfort, optimizing the energy efficiency of a room for better indoor air quality by addressing the minimum ventilation rates proposed. CFD simulations were performed in a office-room of a company located in Porto, Portugal, by a panoply of 10 different scenarios. The analytical determination and analysis of thermal comfort was based upon the standards of ISO 7726 (1998) and ISO 7730 (2005). In summary, this paper has demonstrated that the human rate of occupancy from a typical working office room can be updated for better indoor air quality and thermal comfort by implementing some strategies to achieve better energy performance and maintain occupant thermal comfort. PMV and PPD did not exceeded in all analysed period the daily recommended range of -0.5 to +0.5 and <10%, respectively, for the majority of cases.

Keywords: Indoor air quality, CFD simulation, efficiency, thermoregulation and thermal comfort.

1. Introduction

1.1. *Motivation*

The problem that needs to be solved is the air replacement needs (air quality guarantee) and air conditioning due to the occupation and time of permanence of workers allowing a rationalization of energy resources.

It is crucial to measure the need to ventilate the space, ensuring comfort parameters and legal requirements for occupational health and safety are met.

CFD technique can simulate the needs of ventilation that can help the administrator optimizing the efficiency of an existing ventilated infrastructure and predicting the energetic efficiency of some equipment, as well as helping to understand what adjustments would be need to be made by changing different boundary conditions.

Fluid flows are governed by partial differential equations which represent conservation laws for the mass, energy and momentum. Therefore, the bases of CFD methodology are the Navier-Stokes equations.

CFD uses algorithms to predict how liquids and gases behave and how they work with the products that people design. By understanding the forces and effects of fluid dynamics it is possible to make critical design decisions that improve efficiency and reduce energy consumption.

Also, this type of analysis allows us to understand the heat transfers inside a room and temperature control and airflow management.

1.2. *Objectives of this work*

Based on the previous background, it was tried to understand and to base the methods of numerical simulation that allow to characterize and calculate as accurately as possible the dynamic behavior of an indoor space. The occupants are expected to be a factor affecting the thermal airflow patterns in built indoor spaces. Therefore, it will be verified if the occupancy rate within the interior of a space is a key factor topic of the evaluation.

Initially the study case was selected, which is an office room of an engineering company and it was made a brief description of its internal conditions: number of occupants, physical traits, number of hours of working period, types of materials and their properties, as well as external surroundings: localization and orientation.

The superior and inferior floors were also parametrized and the simulations were then performed comparing different scenarios.

To perform the internal evaluation of the office a software was used for practical reasons of time consuming and expensive measurement equipment.

In this sense, the following parameters were evaluated with the purpose of the experimental characterization of the dynamical behavior inside a building:

- Thermal comfort assessment: simulating extreme situation seasons with different scenarios (winter and summer);
- Thermal local discomfort analysis: vertical air temperature differences, drafts, radiant asymmetries, warm and cool floors;
- Analysis of room air movement and calculating PMV/PPD;
- Daylighting for savings in electric lighting and moisture concentration distribution for better indoor air quality.;
- Air velocity distribution for ventilation effectiveness prediction by performing a CFD analysis;
- Age of air by performing LMA: Local mean age of air.

1.3. *Application of legal standards to the study-case*

ASHRAE Standard 62.1 (2013) defines the primary factors that must be addressed when studying thermal comfort: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity. It is possible for these parameters to vary with time, but metabolic rate and clothing insulation were defined as constant values in this investigation.

ISO 8996 (2004): «Ergonomics of the thermal environment — Determination of metabolic rate» was adopted to specify the metabolic rate of workers inside the office-room.

Extreme situations of temperature were studied and then compared. For selecting values for clothing insulation for summer and winter conditions it was adopted ISO 9920 (2008): «Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble». This International Standard specifies methods for the estimation of thermal characteristics, resistance to dry heat loss and evaporation loss under steady state conditions for an outfit based on known clothing and fabrics.

ISO 7730 (2005): «Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria» was another important document in this research. It is a standard that closely follows the research developed by P.O. Fanger, with the general principals been adapted by ASHRAE in the norm 55: "Thermal environment conditions for human occupancy". This American standard specifies acceptable environmental conditions for the health of people.

ISO 7726 (1998): « Ergonomics of the thermal environment — Instruments for measuring physical quantities» was the standard used to justify the conditions and type of environment of the simulation campaign. This international standard specifies the minimum characteristics of the measuring instruments of the physical variables and also it presents the methods of measurement of those parameters.

It was verified that the physical parameters, air temperature, air velocity and humidity, at a given moment, could be considered to be practically uniform around the occupants.

This can be justified based on the differences between values from table 2 of ISO 7726 multiplied by the corresponding thermal factor X from table 4 of this standard, which were never exceeded in all case of the simulation campaign.

Moreover, this standard helped the current research by justifying the type of environment that was studied.

Therefore, we can have confidence that the office-room of the company is a steady-state example and can be considered as a homogenous type of environment for the application of the current standards.

2. Methodology

2.1. *CFD numerical model*

This paper applied experimentally validated Computational Fluid Dynamics model to investigate air distribution in a typical office room under different combinations of scenarios.

CFD simulations were performed for several cases and parameters such as air velocity, age of air or temperature were calculated and analyzed.

Figure 3 represents the methodology adopted to solution methods for output data.

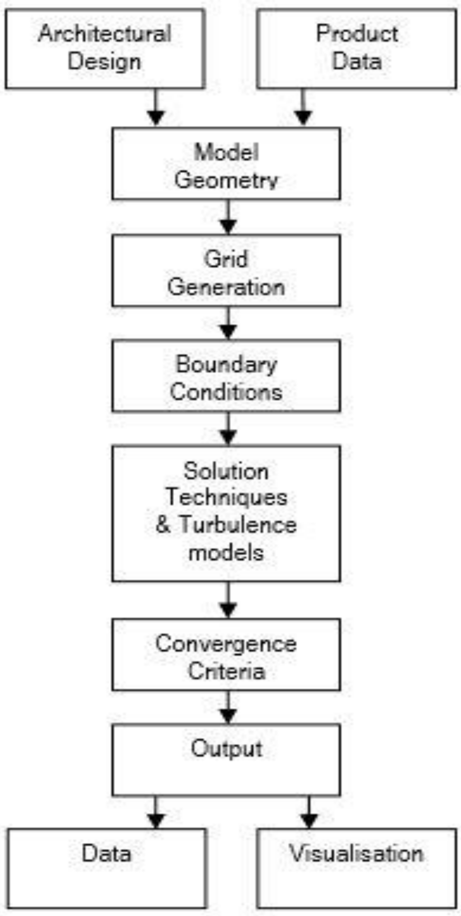

Figure 3: CFD modelling diagram.

Energy Plus was used as a simulation tool, which is a multi-zone dynamic building simulation tool for modeling building, heating, cooling, lighting and ventilating, which allows the development of non-directive studies of the energy savings of a building in the design phase and of existing buildings.

In this paper, studies were performed using Energy Plus software which has been certified by ANSI /ASHRAE 140, using the Design Builder software as a graphical user interface which worked validated calculation algorithm as the basis of this work.

The analysis is divided into two periods corresponding to the conventional heating and cooling seasons.

Algorithms are patterns for completing a task in an efficient way. SIMPLER (Semi Implicit Method for Pressure Linked Equation Revised) was the algorithm for the solution methods.

Turbulence model was set as *k-ε* model which is one of the most widely used and tested for indoor airflow CFD simulation, belonging to the RANS (Reynolds Averaged Navier-Stokes) family of models. Also, it was assumed the air as an incompressible flow.

In the development of the current simulations, it was used the version 8.5 of *Energy Plus* and a licence with version 5.0.3.7 of the *Design Builder* software.

2.2. *Mathematical background*

In order to solve the natural convection air-flow and the heat transfer inside the room, the RANS (Reynolds Averaged Navier-Stokes) and energy equations were numerically solved under the assumption of Newtonian fluid and incompressible flow.

A three-dimensional steady-state numerical analysis was performed in a typical office room at which it was applied experimentally validated CFD model.

The numerical method used by Design Builder involves the solution of a set of equations that describe the conservation of heat, mass and momentum to evaluate indoor air quality and thermal comfort.

Navier-Stokes equations were used to model airflow and heat transfer and further to computationally evaluate the air change rate.

These equations represent the conservation of momentum, while the continuity equation represent the conservation of mass.

$$\frac{\partial \rho}{\partial t} + \nabla . \ (\rho \vec{u}) = 0 \qquad (1)$$

The general form of the governing equations is as follows:

$$\frac{\partial(\rho\Phi)}{\partial t} + div\left(\rho\,\vec{V}\,\Phi\right) = div\left(\Gamma_{\Phi}\,\overrightarrow{grad}\,\Phi\right) + S_{\Phi} \qquad (2)$$

This equation represents the conservation of Φ which symbolizes each of the three air velocity components u, v and w, the turbulence kinetic energy k, the turbulence dissipation rate ε and the temperature T. In this equation:

- $\frac{\partial(\rho\Phi)}{\partial t}$ – represents the variation in time of the quantity observed, where ρ is the density of the support fluid.
- $div\ (\rho\,\vec{V}\,\Phi)$ - is the net quantity brought by the flow of velocity through the surface of an elementary unity control volume representing the convection process.
- $div\ (\Gamma_{\Phi}\,\overrightarrow{grad}\,\Phi)$ - where Γ_{Φ} represents the diffusion coefficient of Φ within the support material, is the next flux of Φ quantity diffused through the surface of the elementary control volume.
- S_{Φ} - is a source term which represents the creation of Φ per unit of volume and time.

All fluids are compressible, some more than others, and almost all fluids expand when heated, which means their density depends on absolute pressure and temperature through a thermodynamic relation: $\rho = \rho\ (p\ A,\ T)$.

However, from a practical point of view, most fluids can be safely described having a constant value of ρ (density) which is the case of incompressible fluids.

Table 2: Coefficients of the governing mathematical equations.

Equation	Φ	Γ_{Φ}	S_{Φ}
Continuity	1	0	0
X momentum	u	μ	$-\frac{\partial P}{\partial x}$
Y momentum	v	μ	$-\frac{\partial P}{\partial y} - g\rho$
Z momentum	w	μ	$-\frac{\partial P}{\partial z}$
Turbulent kinetic energy	k	$\frac{\mu}{\sigma_k}$	0
Dissipation rate of turbulent kinetic energy	ε	$\frac{\mu}{\sigma_\varepsilon}$	0
Enthalpy	$C_p T$	λ	S
Concentration	$\frac{c}{\rho}$	d	S_c

2.3. *Natural ventilation rate*

Since people spend 80 to 90% of their time inside buildings, it becomes crucial studying the most efficient way of building ventilation. The growing concern about energy efficiency of buildings makes their thermal performance improvement a very current concern.

The main reason for having ventilation requirements is human health and building conservation. Interior of buildings are composed by variety materials with different pollution loads.

To determine the required ventilation, the following factors must be taken into account: location, building dimensions, number and type of building occupants and their activities, heat supply by the equipment and solar radiation, relative humidity, outside air and temperature variation.as heat sources.

In the present work it was adopted the minimum acceptable ventilation rate defined by Portuguese legislation which is 0,40 renovations per hour - a value defined by REH -«Regulamento dos Edifícios de Habitação».

3. Case study simulation description

3.1. *Geometry and boundary conditions*

To start the simulation process, it is required for the user to input some data in relation to the description and constitution of the building that is represented by figure 4.

The company's office-room studied is located at the first floor of the building of an engineering company located at Vila Nova de Gaia, Porto, in Portugal.

The dimensions of the study-case are: a ceiling height of 2.93 m, an area of approximately 35.13 m^2 and a gross volume of 103.00 m^3. The geometry of the studied and parametrized plant and 3D view is outlined in figure 4 and figure 5, respectively.

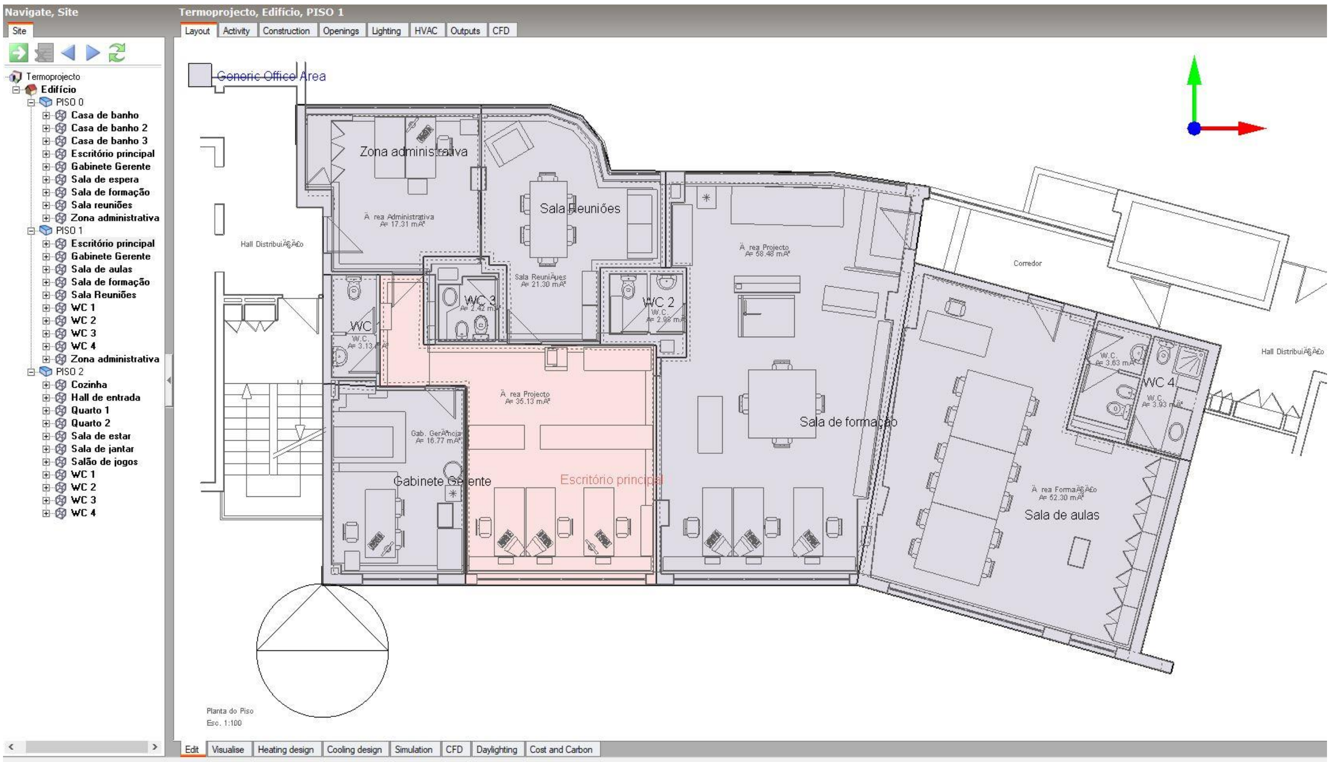

Figure 4: AutoCAD 2D plan of the selected company.

The «weather file» selected describes the environment surrounding the building. *Energy Plus* was set with the localization of Vila Nova de Gaia, Porto, Portugal, with the main office-room facing North.

Both superior and inferior levels were also parametrized with types of materials, openings and occupancy. The office room for analysis was at the located at the first floor of the building.

Proper specification of internal and external boundary conditions are crucial to obtain a solution for the discretized Navier-Stokes equations.

After creating the geometric model and defining the boundary conditions at Design Builder, other parameters were as well characterized and parametrized in the Design Builder software such as materials and ventilation system of the main's office room which is our study-case .

3.2. *Number of occupants*

After creating the geometric model and defining the boundary conditions at Design Builder, it is necessary to identify each zone and its associated activities.

The identification of the activity as well as defining the number of occupants and specific heat sources (lighting, computers, radiators) within each zone has a great influence on the majority of internal thermal gains, thus influencing the heating, cooling and or ventilation requirements.

The number of occupants was defined by a value of density (number of occupants/ m^2) for each zone. All indoor spaces were parametrized in function of the estimated human density rate as showing in table 3. The value of the main's office room of occupants per square meter presented in table 3 is considered to be the most common value of the worker's daily journey.

Therefore, the main office's room number of workers was variable throughout the simulation process (1,3,6,9 and 12 occupants).

Table 3: Rate of occupancy selected.

Indoor space	Occupants/m^2
Administrative zone	0,0596
Manager's office	0,0578
Main office room	0,0854
Training room	0,0000
WC's	0,0030
Reunion room	0,0496
Classroom	0,0500

3.3. *HVAC and lighting*

To complete the design of our model, it is necessary also refer lighting and HVAC systems. Then, the CFD simulation of the case study was performed.

Design Builder has predefined templates that, like the activity parameter, can be selected according to the zone to which they are intended. In this way the program automatically associates the lighting performance and the respective energy consumption depending on the selected zone.

3.4. *Activity and properties of the main office-room*

For this current work, the occupant is assumed to be performing «light» work in the main office-room which is the focus of the study.

The selected room (main office-room) of the company for analysis is the indoor space which has more human movement all day long, being almost all time with the occupation of 3 workers.

The most common value of the worker's working journey is 3 occupants in the main office-room, so this is the value considered in the final CFD output results.

Also, through detailed analysis the capacity of doubling the number of workers was tested by simulating 6 workers for the same period of work, then 9 and finally 12 workers.

Figure 5: 3D Building 3D layout.

The Metabolic rate for office sedentary activity considered for all workers was 70 W/m^2 (1,2 met) according to ISO 7730 (2005).

A local thermal resistance for clothing insulation was fixed to 0.5 clo for summer and 1.0 clo (1 clo = 0.155 m^2.K/W) for winter at person air/interface option of the software.

An important feature in calculating heat flows is the existence of any type of ventilation (mechanical, natural or hybrid).

Therefore, it was considered the minimum value of 0,4 rph. In the common use of the office-room it is allowed a natural ventilation which is the preferred ventilation system and it can supply the air replacement needs by the minimum value of 0,40 renovations per hour.

Table 4 represents the main properties of the office-room.

Table 4: Properties of the main office-room.

Parameter/Element	Properties/Material
Computer (3 fixed computer and 3 portable computer)	Constant heat flux resulting in total heat of 12 w/m^2
Floor	Wood
Ceiling	Plasterboard
Interior walls	Masonry
External walls	Brick and concrete
Windows	Double glazing
Lighting	Constant light load of 9 W/m^2
Infiltration rate	0,04 h^{-1}
Ventilation rate (without heat recovery)	0,4 rph

3.5. *Simulation scenarios*

Simulations were performed for studying the influence of human occupancy in extreme thermal conditions: winter and summer. It was chosen the month of January and August for the coolest and hottest weeks of the year.

Table 5 represents a brief summary of all simulated cases in the main office-room.

Ten different scenarios of simulation were performed. These simulations considered only occupied periods by workers with a schedule of work between 8:00 h until 12:00 h and 13:00 h until 17:00 h, excluding weekend days.

Simulation Cases	Number of occupants	Conditions
S1	1	Summer
S2	3	Summer
S3	6	Summer
S4	9	Summer
S5	12	Summer
W1	1	Winter
W2	3	Winter
W3	6	Winter
W4	9	Winter
W5	12	Winter

Table 5: Summary description of simulation cases.

3.5.1 *Selection of data and convergence of the results*

In this topic it was selected the second month of August as the hottest month of summer and January as the coldest month of winter in order to compare both extreme situations.

It is really important to ensure that the numerical results are stable and converged by not exhibiting transient behavior due to instabilities in the flow in analysis which was confirmed by the CFD calculation in a grid of 0,35 and with 0,035 default grid tolerance.

To sum up, there is a high level of confidence in the results output obtained from Design Builder as the methods and model selected have successfully converged as figure 6 demonstrates.

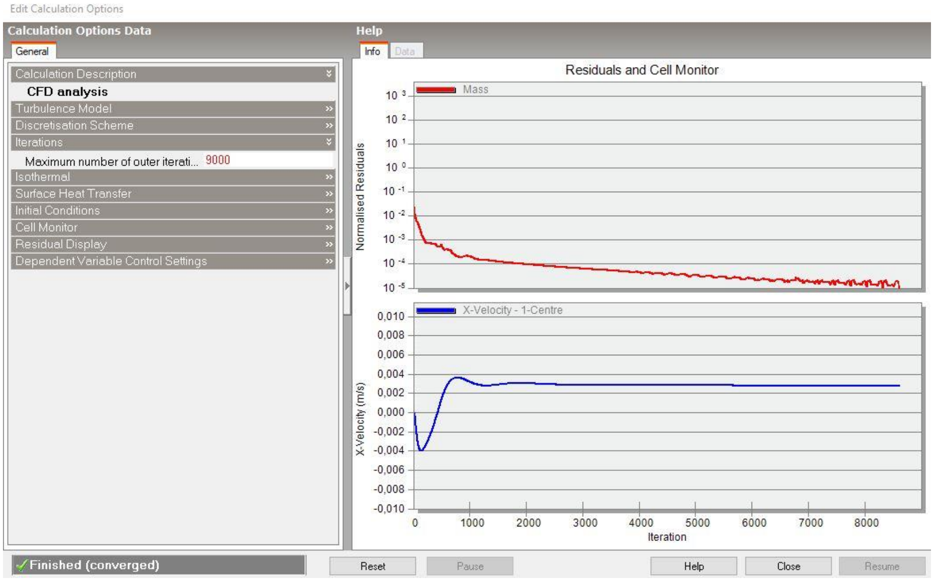

Figure 6: Convergence of the model selected initially.

4. Results and discussion

4.1. Temperature distribution

This section is devoted to numerical results presentation and to discussing and point out the principle aspects derived from the numerical investigation.

The CFD option of Design Builder allows to perform 3D graphics for velocity, temperature, pressure and air age distribution within the study area as well as calculates comfort indexes (PMV and PPD), average radiant temperature and operative temperature which are requirements for satisfying thermal comfort and IAQ according to ISO 7730 (2005).

4.1.1 *Indoor and outdoor air temperature analysis*

Indoor temperature is one of the main characteristics of an indoor environment. The indoor temperature affects several human responses, including sick building syndrome symptoms, perceived air quality, thermal comfort and performance at work (Kim, J. and R. de Dear, 2012).

The interpretation of results is referring to indoor air temperature, radiant temperature, operative temperature and dry bulb temperature of the air outside the building.

Figure 7 represents an interior and exterior temperature distribution with relation for the coldest month.

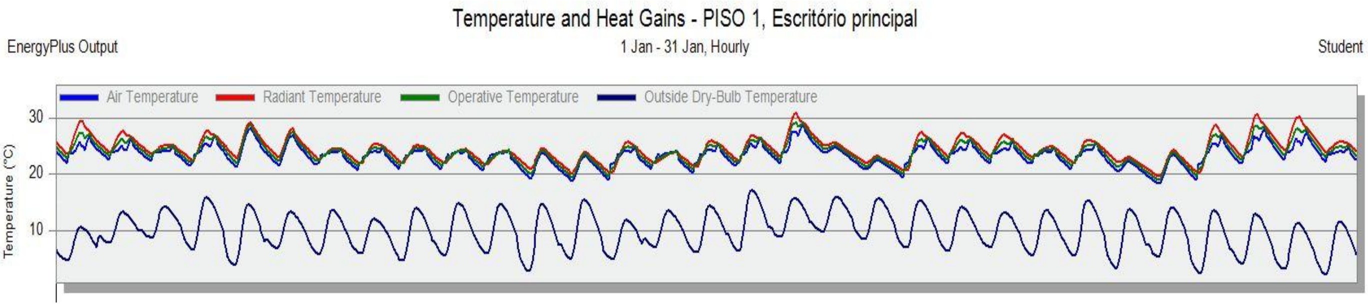

Figure 7: Main office’s temperature distribution for the coldest month.

Figure 8 represents an interior and exterior temperature distribution relatively to the coldest month.

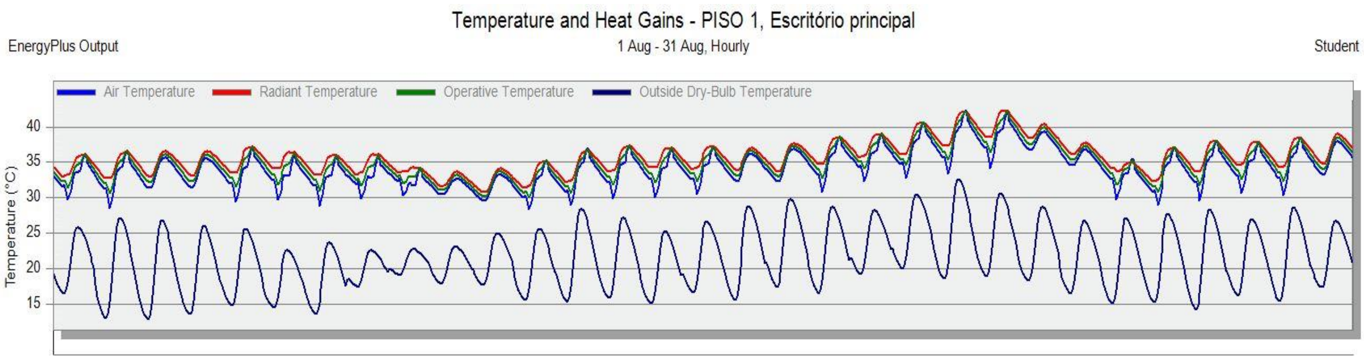

Figure 8: Main office’s temperature distribution for the hottest month.

4.1.2 *CFD indoor air temperature analysis*

Indoor air temperature at the office-room was analysed as figure 9 demonstrates by selecting two different slices of the room that included the common location of the workers inside the space.

The two slides were specially located where the chairs of the occupants exist, as it is a sedentary work and they're sitting almost all the time of the working day.

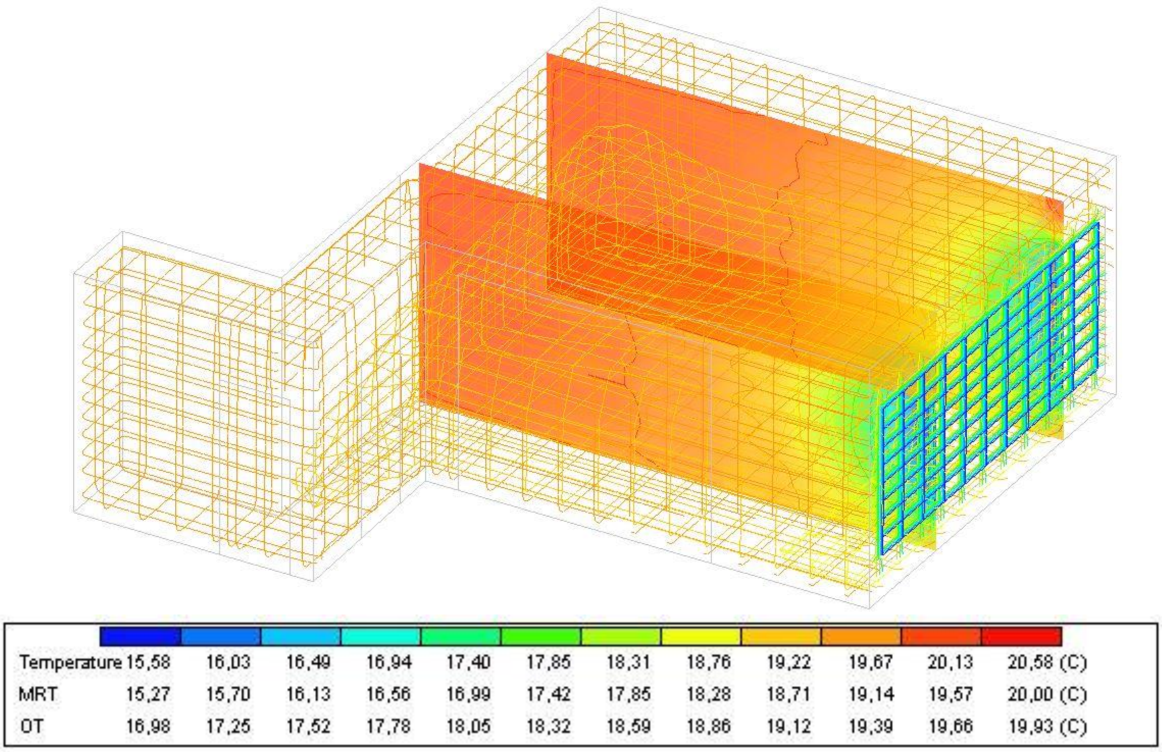

Figure 9: Main office's temperature distribution – 3D view.

Figure 10 shows the current air temperature distribution for a typical working day inside the office-room. The legend below the figure indicates all different temperatures with Temperature being the actual indoor air temperature inside the office-room, MRT corresponding to mean radiant temperature and finally, OT being the operative temperature.

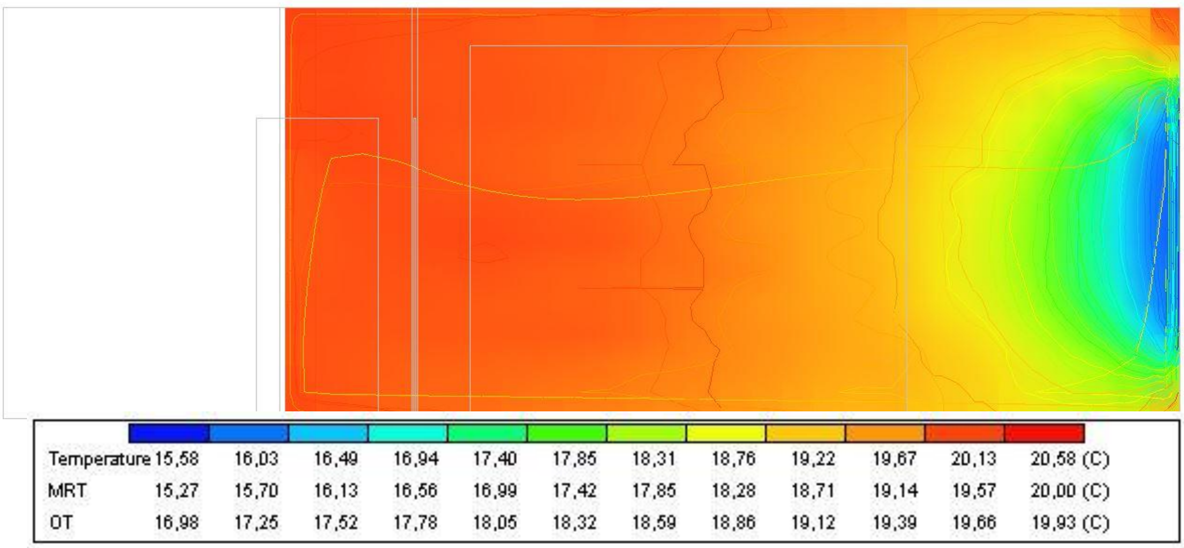

Figure 10: Main office's temperature distribution – left view.

Figure 10 shows a decrease in the interior air temperature of the room due to the existence of an open window (boundary condition defined in the DB input data).

4.2. Thermal comfort

In this study, the metabolic rate is set to 1.2 met. This value represents sedentary office activities and the clo value is set to be 0.5 for summer conditions and 1.0 for winter conditions.

The methodology for calculating our reference points:

- To evaluate the thermal comfort level of the office-room and compare with ASHRAE 55 and ISO 7730.
- PMV: This index is no more than a quantitative scale of the sensation of heat and cold. It represents the thermal sensation voted by a large number of people exposed to a certain environment.
- PPD: A percentage of people dissatisfied thermally, which can be determined based on the value of the predicted mean vote - PMV.
- To determine local thermal discomfort of workers in the office environment by measuring 3 important causes: vertical air temperature difference between head and ankles, range of floor temperature and radiant temperature asymmetry.

4.2.1. Thermal Comfort Analysis with Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD)

The verification of ISO-7730 requires measurements of thermal parameters. Thermal comfort of the office room zone can be evaluated by calculating the PMV as proposed by Fanger (ISO 7730 - 2005).

This index is the average thermal sensation of a large group of people in a given environment is expressed through a mean vote that follows the scale presented in table 6.

Table 6: ASHRAE Thermal Sensation Scale: PMV Index.

-3	Cold
-2	Cool
-1	Slightly cool
0	Comfortable
+1	Slightly warm
+2	Warm
+3	Hot

An equation was developed that makes it possible to calculate the PMV from the input of the environmental variables (temperature, velocity and humidity of the air and average radiant temperature), of the clothes and the activity of the occupants.

In this study, only occupied periods by workers at the office were evaluated considering weekend days off.

Assuming that the thermal sensation of each of these individuals was a function of the heat demand to which they were exposed, Fanger P. O. (1972) calculated this request for all situations and correlated it with the comfort vote.

As the thermal request is a function of the environmental, clothing and activity variables, it was possible to find the relation between all these parameters and the average comfort vote given by the people, in the most varied situations.

In order to make this index more significant, Fanger P. O. (1972) proposed a relation between the PMV with the degree of user dissatisfaction. Using the experimental data and considering as unsatisfied people who voted above -2 (cold) or +2 (hot), it was obtained the graphic, from which it was developed the equation 4.

The PMV is the most widely used and known comfort index in the world. This model forms the basis for the international ISO 7730 standard [13], which establishes the conditions for thermally moderate environments in which people perform light activities.

Therefore, it is possible to calculate PPD by knowing the PMV values, with the next equation:

$$\mathrm{PPD} = 100 - 95 \cdot \exp(-0{,}03353 \cdot PMV^4 - 0{,}2179 \cdot PMV^2) \qquad (4)$$

Figure 11 represents the PMV results for the occupied working period of the hottest month of the all year, in this case, the month of August. It is possible to verify that PMV increases with the number or workers.

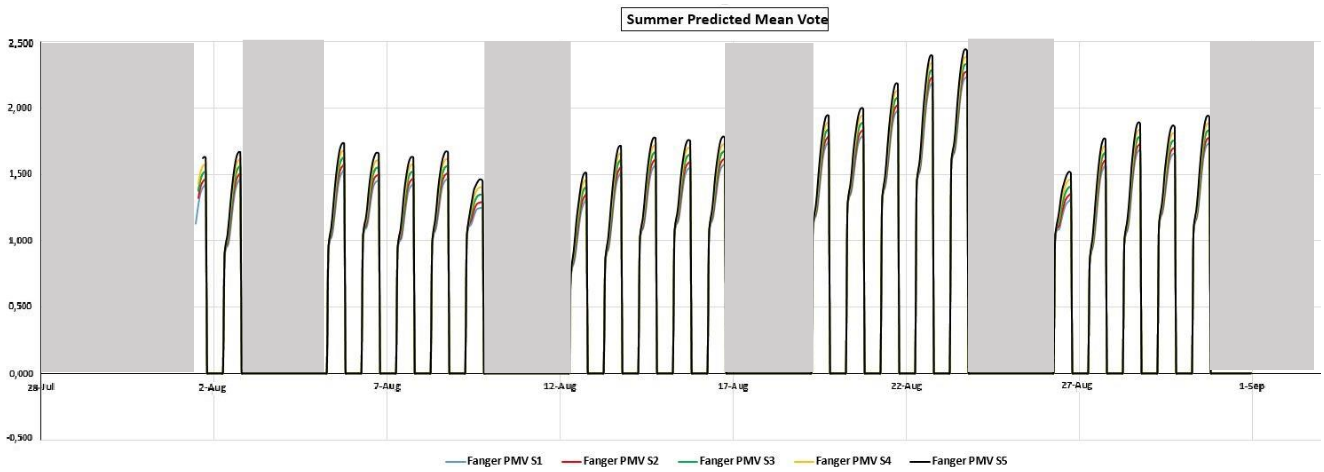

Figure 11: Summer hottest month predicted mean vote.

The grey area represented in both figures 11 and 12 has the meaning that nobody is inside the office-room, so there is no PMV value for those periods.

Figure 12 represents the PMV results for the occupied working period of the coldest month of the all year, in this case, the month of January. The values ideally would be around 0 which traduces the best value of PMV for the thermal comfort but when nobody is at the office it can be interpreted with no vote.

When the average vote is equal to zero, there is an average of 5% of people dissatisfied, which indicates that it is impossible to guarantee comfort for the entire occupying population.

Figure 11 shows that for the first simulations, from S1 (only one worker) until S5 (12 occupants), for the cooling season situation, the maximum values ranged from 2.22 until 2.44. The last value corresponds to a percentage of approximately 80% of dissatisfaction.

Regarding the coldest month of the year, in this case, January, illustrated in figure 12 there is a maximum value of PMV equivalent to 1.00 for the simulation case W5 which has 12 occupants and its a minimum value equal to -0.180.The level of discomfort can be represented by the PPD index, which was approximately 27% for the worst scenario.

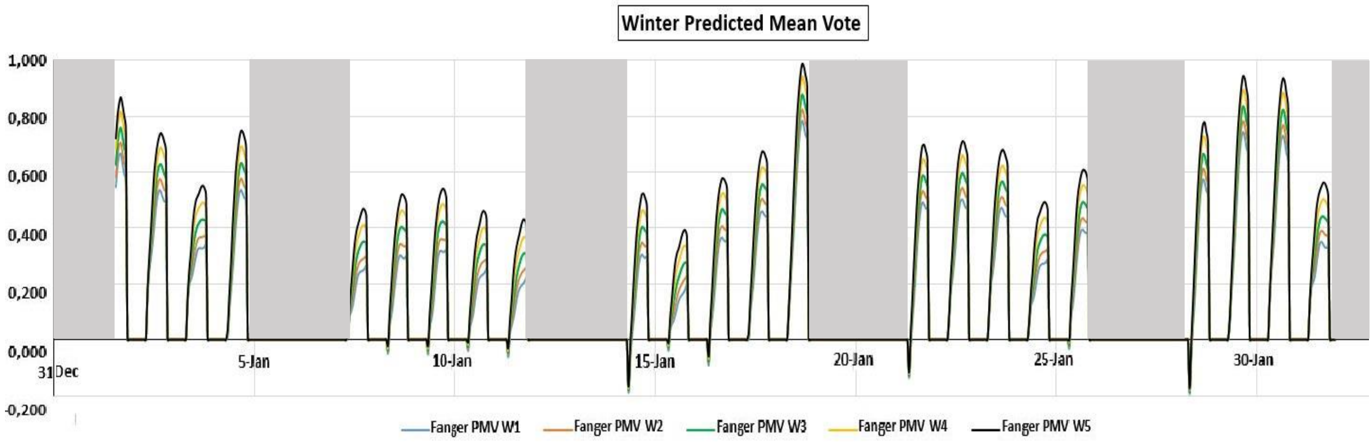

Figure 12: Winter coldest month predicted mean vote.

Table 7 represents a summary description of every simulation scenario performed. The values presented in this next table represent average monthly values obtained for the extreme situations, both winter and summer.

Table 7: Summary description of all cases.

Simulation ID	PMV	PPD (%)
W1	0,168	5,50
W2	0,200	6,00
W3	0,231	6,50
W4	0,256	7,00
W5	0,287	7,50
S1	0,485	9,50
S2	0,495	10,00
S3	0,511	10,50
S4	0,525	11,00
S5	0,540	11,50

It is possible to verify that only 3 scenarios (S3, S4 and S5) exceed the mean PMV limit of a comfortable environment defined by ASHRAE which is between -0,5 and 0,5 and with the PPD being under the 10% value.

4.2.2 Local thermal discomfort

The evaluate the thermal comfort in indoor environments is not enough to analyse the comfort conditions but also to consider the local thermal discomfort specifications.

Local thermal discomfort occurs due to factors that change the homogeneity in the environment. These factors may be due to vertical temperature differences of air, air currents, windows or hot or cold surfaces.

Conditions of local thermal discomfort are normally due to asymmetries of radiant temperature, vertical air temperature difference between ankles and head and also the range of floor temperature.

Figure 13 presents for 17th january, a typical working day inside the office-room, two slices with the distribution of indoor air temperature at a height of 1,10 m (upper slice) and 0,10 m (lower slice) as it is recommend by ISO 7730 (2005).

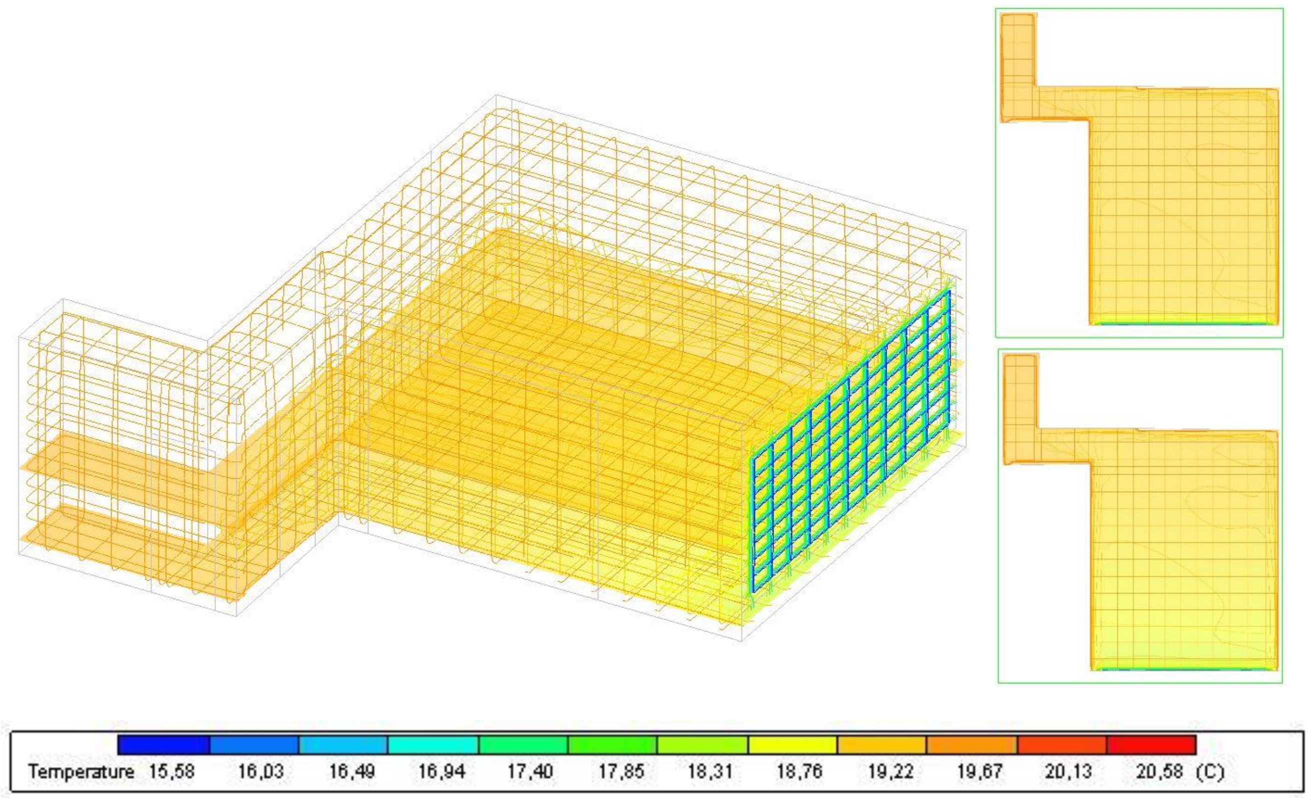

Figure 13: Analysis of vertical air temperature difference between head and ankles.

Generally, indoor air temperature increases from floor to ceiling. If this increase is too high, local discomfort may be expressed by heat in the head and cold in the feet, although the entire body is in a situation of comfort. ISO 7730 (2005) specifies a maximum temperature limit difference between ankles and head which is 4ºC for category C, 3ºC for category B and 2ºC for category A.

To sump up, there is no local thermal discomfort caused by vertical air temperature differences for this specific day in the office-room.

A second topic to be approached in ISO 7726 (1998) is the radiant temperature asymmetry. Thermal radiation around occupants may not be uniform due to either hot or cold surfaces as well as direct solar radiation. This asymmetry can cause local discomfort and reduce the thermal acceptability of the environment.

In general, people are more sensitive to asymmetric radiation caused by warm ceiling or cool walls (ISO 7730). In section 6.5 of ISO 7730 it is mentioned that the measurement of radiant temperature asymmetry is given by the difference between the flat radiant temperatures of two opposite sides of a small flat element. It should be measured at the height 0.60 m for people sitting and 1.10 m from the floor, for people standing (ISO 7726).

By studying temperature graphics in office-room ceiling and walls with the help of Design Builder software it was concluded that there are no local thermal discomfort due to radiant asymmetries as the mean temperature values of opposite elements remain practically constant respecting the values of table A.4 of the respective standard for both winter and summer conditions.

Finally, occupants may fell discomfort in their feet, even with shoes, due to the direct contact with the floor, if it is cold or hot which is limited by a maximum and minimum range of floor temperature (ISO 7730).

In the heating season, winter, the floor temperature mean value is of approximately 24ºC which is a value that respects the maximum and minimum acceptable values of table A.3 of ISO 7730. This means there is no local thermal discomfort due to the range of floor surface temperature.

Nevertheless, for summer conditions, there is local thermal discomfort with the normal rate of occupancy (3 occupants) due to the range of floor temperature because the mean value is 32º C, which clearly does not respect the maximum allowable limit value for the temperature range.

4.2.3. Air Change Effectiveness - ACE

Air change effectiveness is not the same as ventilation effectiveness. It is a description of the air distribution system's ability to deliver ventilation air to an indoor space or zone within the building.

Figure 14 represents the selection of the 12 positions for workers contemplated in the previous cases of simulation which are around the two existing tables provided with the computers.

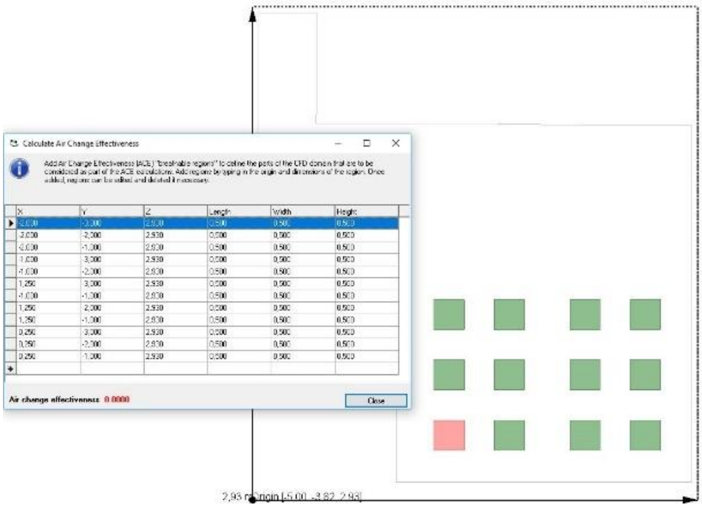

Figure 14: Air change effectiveness.

4.2.4. CFD Analysis

Figure 15 represents a type of CFD analysis performed with Design Builder inside the main office-room, by selecting two different slices of the room that included the common location of all the workers inside the space on 17th january, a typical working day.

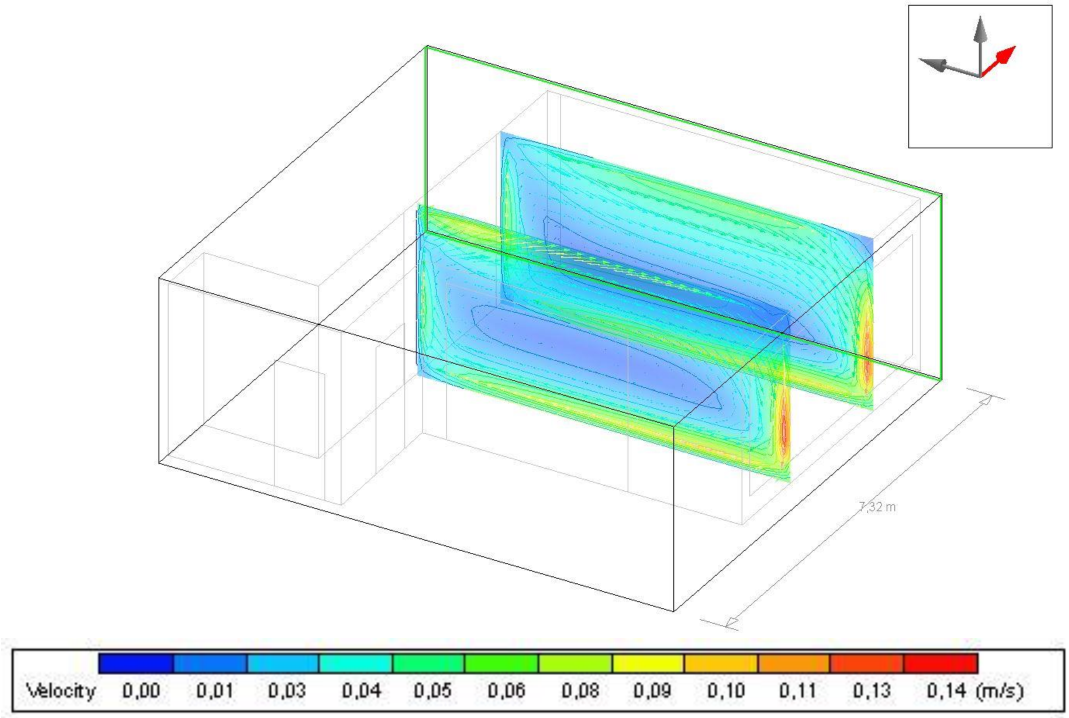

Figure 15: Office-room air velocity distribution.

In the previous image - figure 15- it is shown the air velocity distribution for the main office room.

Figure 16 shows a zoom for air velocity distribution of one those slices chosen in the main office's room.

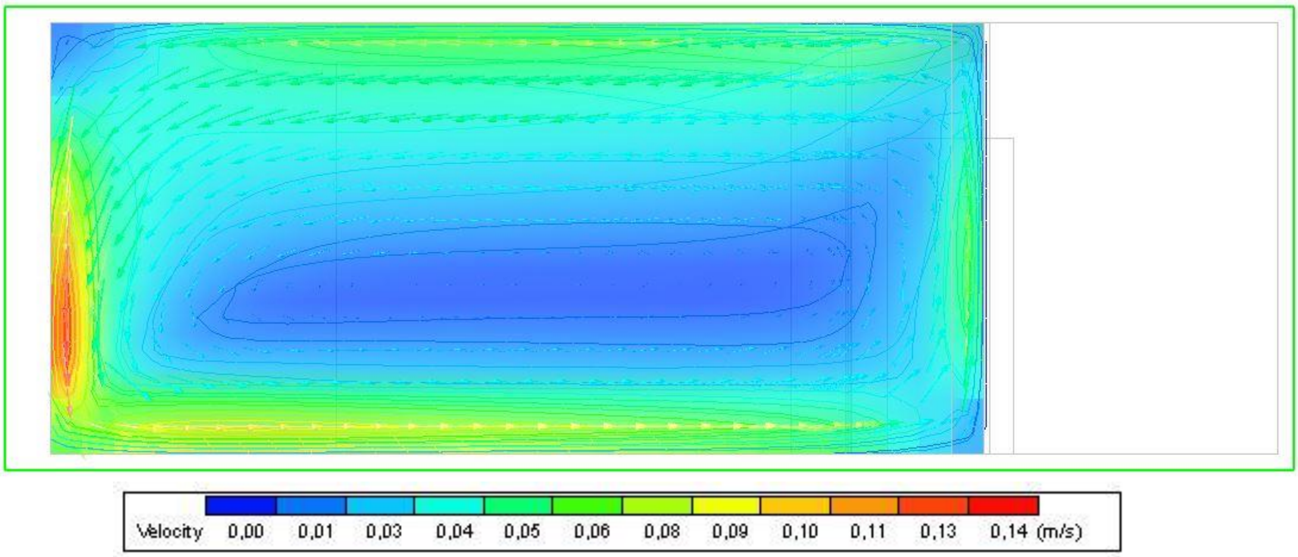

Figure 16: Office-room air velocity distribution – right view.

ISO 7730:2005 defines for summer conditions a maximum value of air velocity 0.24 m/s and for winter conditions a maximum of 0.21 m/s. By a quick analysis to the previous image we can conclude that all of these values are respected.

During the cooling season (summer) and the heating season (winter) it was possible to verify that air speed did not exceed the legal limit values for both situations

Figure 17 demonstrates the distribution of the indoor air velocity in meters per second with a different perspective – the plan view.

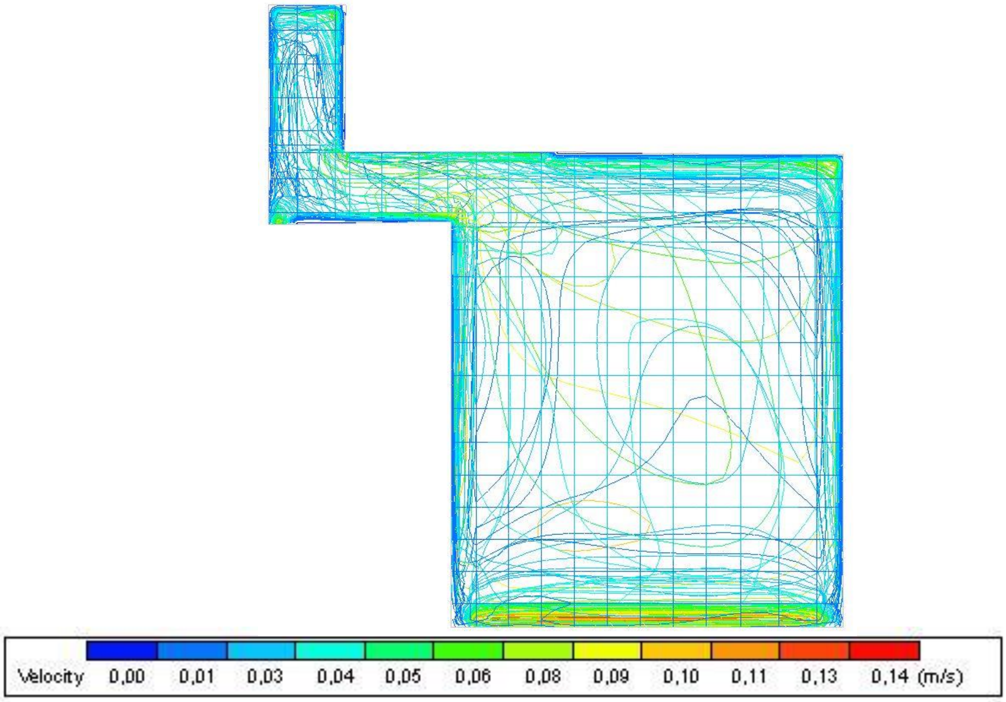

Figure 17: Office-room air velocity distribution **-** plan view.

It is possible to see in the previous image that greater air velocity values are in the zone of the existence of the opened window where the air flow and ventilation rate are greater too.

Finally, it is presented by figure 18 the 3D perspective of airflow management, to understand the air speed vectors as function of the interior space.

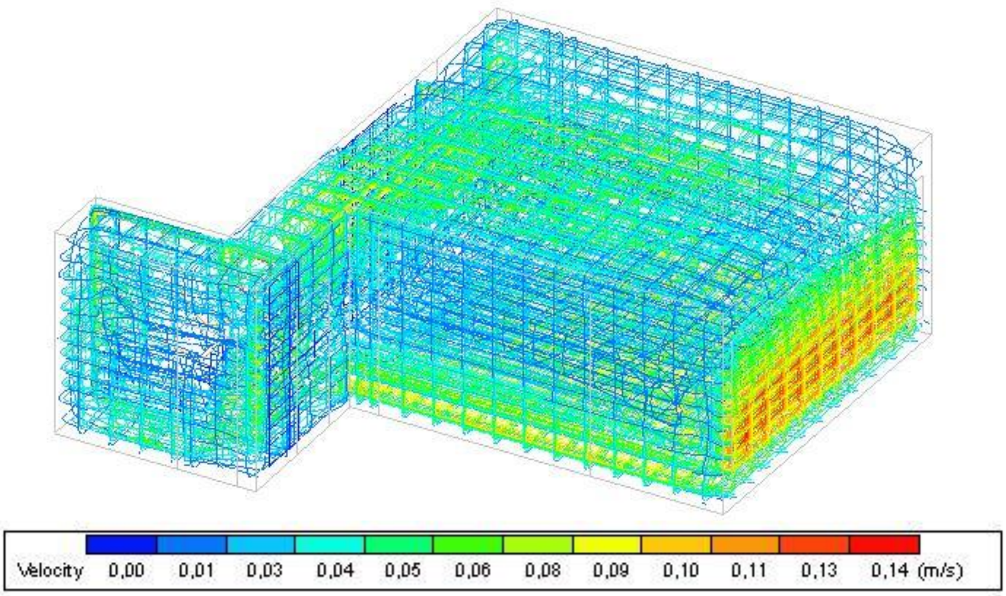

Figure 18: Office-room air velocity distribution **-** 3D view.

4.2.5. Local Mean Age of Air – LMA

The age of air of a single room is the average time elapsed since molecules of air at that location entered the building.

To determine the age of air and air exchange effectiveness it was performed an LMA (Local Mean Age of Air) analysis by Design Builder.

Figure 19 presents this type of calculation of the age of air distribution within the main office's room with mean values.

Nevertheless, it is possible to verify in this 3D image that the corridor zone is the area within the office room with the poorest IAQ as it is the zone with the greatest age of air which can also be associated with low air velocity shown in figure 16 and figure 17.

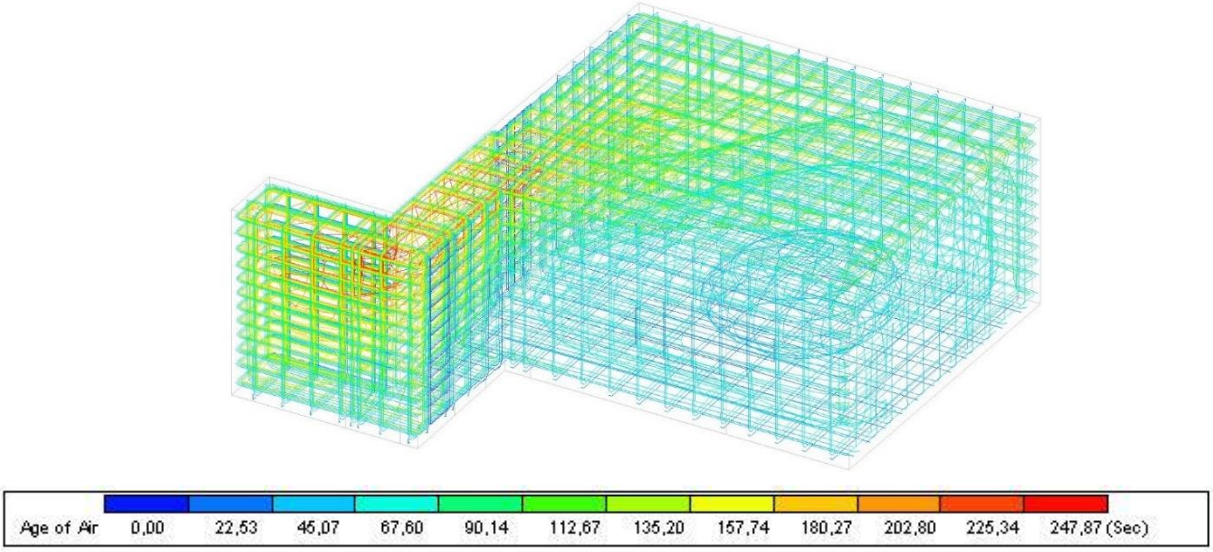

Figure 19: Office-room's Predicted Age of Air (s) – Axonometric 3D view.

Figure 20 represents the plan view for better understanding of the age of air parameter at a height of 1,70 m. This can be related with IAQ. The higher the age of air gets the lower and poorer the indoor air quality.

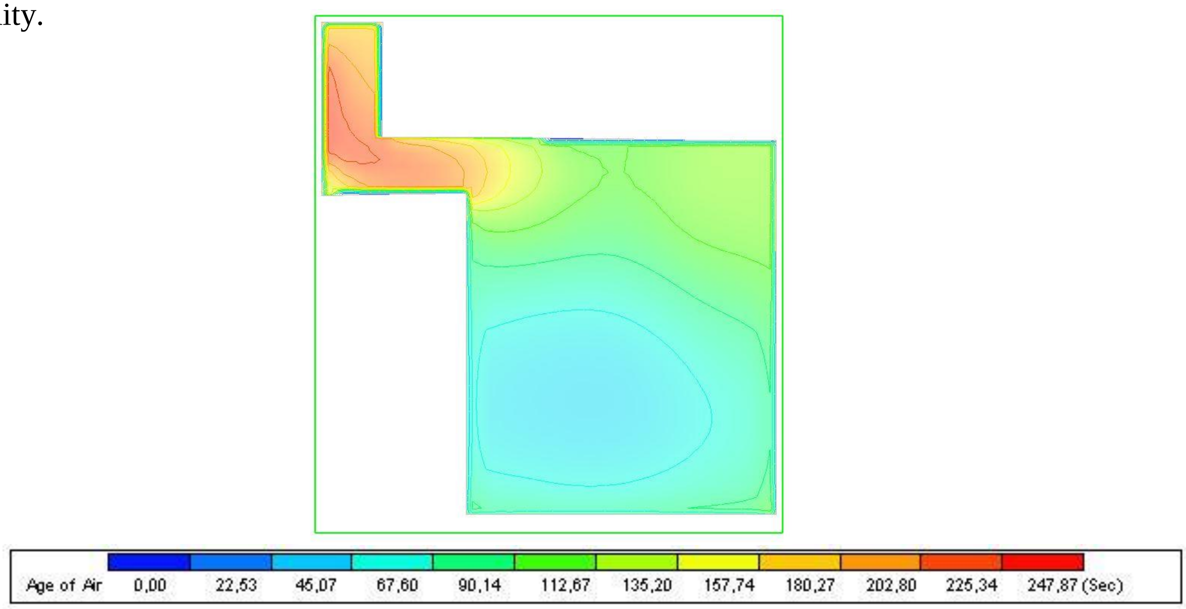

Figure 20: Office-room's Predicted Age of Air (s) – Plan view.

5. Conclusions and future developments

Design Builder stands out the simulations, which present great reliability in the results, besides having resources that contemplate dynamic phenomena in buildings, according to usage patterns, such as the level of activity, type of materials, level of shading devices ventilation and air temperature.

There is a high degree of confidence in all results as all solutions of the main CFD calculations have converged quickly to a final solution.

In the organization of building space, it is important to employ the concept of thermal zoning to create a rational distribution of heat and reduce thermal losses. One way to achieve this is to locate the most energy-demanding spaces on the south facade and place the other spaces on the north side of the building. It is at the level of indoor spaces that the requirements of thermal, visual, acoustic and air quality are taken into account.

Nevertheless, the selected office room was north-facing, so, the amounts of radiation received during winter were negligible.

Output data of the main office obtained by Design Builder showed that the office had thermal conditions falling within the comfort zone of the studied standards with some exceptions.

However, in the summer period, the comfort requirements are always met by the real occupancy (3 workers) but for 6 occupants or more, there is a degree of discomfort.

For the heating season this situation is not critical for the maximum occupancy rate considered in this study.

The heating, ventilating and air-conditioning (HVAC) system determines energy and air exchange in buildings. Occupants also contribute to the indoor room's climate conditions by exchanging energy with the building.

In the present study, no mechanical ventilation was observed at the office room, therefore only natural ventilation was considered. Ventilation rates mandated by standards and regulations can have a huge impact upon the energy consumption in a building.

Providing the windows with adjustable ventilation devices to allow opening in the summer and closing in the winter allowing a greater air change effectiveness and consequently an improvement in thermal comfort, as well as air quality.

Two crucial criteria must be considered in every efficient healthy building design which consist in maintaining good thermal comfort and providing a good indoor air quality. This article presents a numerical study of IAQ and thermal comfort that can be achieved every time.

In winter, when the outside temperature presents almost always values below the comfort conditions, it is important to limit infiltration. However, inside buildings, renewal of indoor air is a necessary measure to maintain the minimal indoor air quality conditions and a suitable level of ventilation which must always be ensured through a suitable natural, mechanical or hybrid ventilation system.

In the summer period, natural ventilation plays an important role in the cooling of buildings, especially at night. In this sense, the air circulation contributes to the decrease of the internal temperature and also to the removal of the sensible heat stored in the thermal mass. Ventilation also has implications in terms of thermal comfort, by encouraging heat loss through convection and evaporation in occupants.

Simulation results showed that the office-room had acceptable thermal conditions according to ASHRAE standard 55 and ISO 7730 in terms of interior air velocity and temperature with the exception of 3 scenarios.

In terms of natural ventilation, it was concluded that the air exchange effectiveness value in office is optimal and the ventilation is well mixed

For future investigation, CFD analysis could be made for more rooms, rather than just one, to understand the flow changes between the various adjacent rooms. Figure 21 represents an example of a CFD analysis an adjacent room to the study case of this paper which is the manager's office-room.

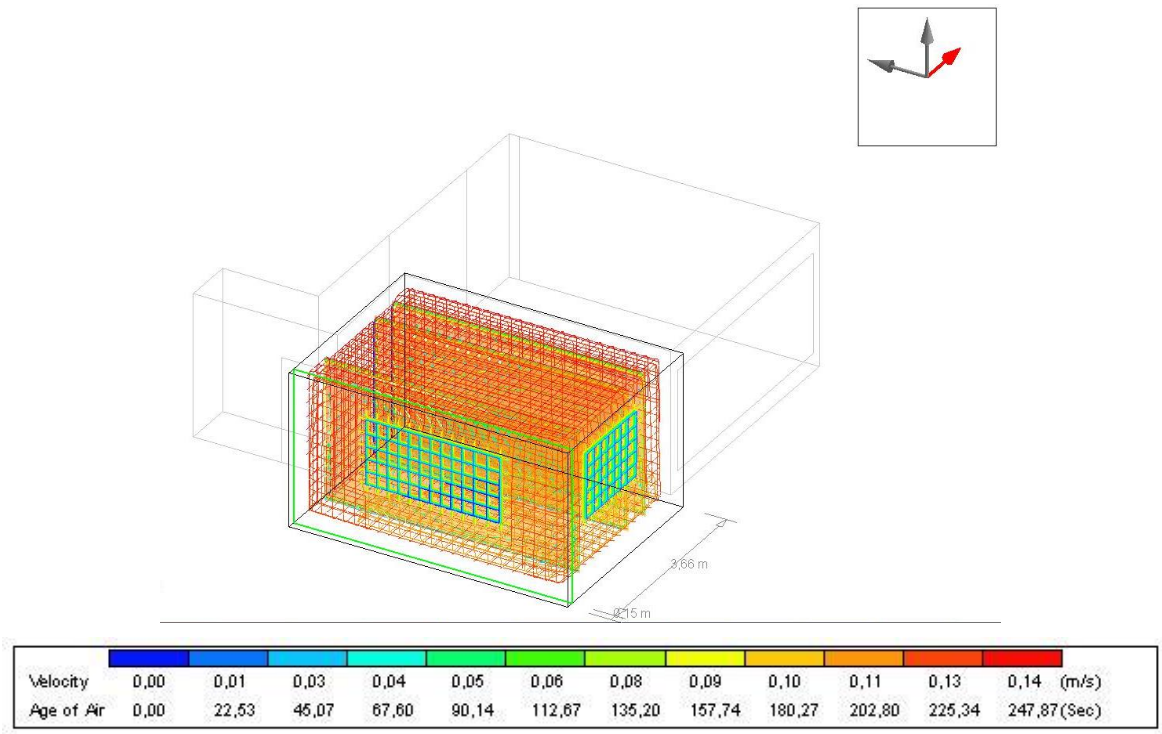

Figure 21: Manager office-room's Predicted Age of Air (s) – 3D view.

6. References

ASHRAE Standard 55-2004: Thermal Environment Conditions for Human Occupancy, American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), 2004

ASHRAE 62.1, Thermal Environmental Conditions for Human Occupancy. 2004

Eurostat, 2017. Buildings - Energy Efficiency.

EN15251, Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings – Addressing Indoor aur Quality, Thermal Environment, Lighting and Acoustics, English version, 2007

EN 1379, Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems.

Fanger, P. O. (1972). Thermal Comfort: Analysis and Applications in Environmental Engineering. New York: McGraw-Hill Book Company, 244.

Guedes, J.C., Santos Baptista, J. & de Carvalho, J.M., 2014. 3D human thermoregulation model: Bioheat transfer in tissues and small vessels. In G. Arezes, PM and Baptista, JS and Barroso, MP and Carneiro, P and Cordeiro, P and Costa, N and Melo, RB and Miguel, AS and Perestrelo, ed. *Occupational Safety and Hygiene II*. Guimarães: Taylor & Francis, pp. 669–673.

Huang, K.D. & Tuan, N.A., 2010. Numerical analysis of an air-conditioning energy-saving mechanism. *Building Simulation*, 3(1), pp.63–73.

ISO 7730. Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva: International Organization for Standardization, 2005.

ISO 16000-Part 8. Determination of local mean ages of air in buildings for characterizing ventilation conditions, 2007.

ISO 7726. Ergonomics of the thermal environment — Instruments for measuring physical quantities, 1998.

ISO 8996, Ergonomics of the thermal environment - Determination of metabolic rate, 2004.

Kim, J. and R. de Dear, Impact of different building ventilation modes on occupant expectations of the main IEQ factors. Building and Environment, 2012. 57: p. 184-193

4. FINAL REMARKS AND WORK LIMITATIONS

There are substantial reductions in time when performing a CFD analysis. Also, there is the advantage of the ability to study different systems with small changes between them within a space.

In this study, grid resolution was set to be 0,35 of spacing and the model converged reasonably well with 9000 iterations. Increasing the number of grid points would automatically increase the accuracy of the results.

However, it would also increase the time it takes to perform CFD simulations. Therefore, there is a high trust level in all results as all solutions of the main CFD calculations have converged reasonably well.

Results are reliable on the CFD output data with no other type of equipment used for measuring the physical parameters of analysis.

Nevertheless, measuring equipment such as a laser distance sensor was used in the begging of this research to parametrize posteriorly the building in the software with its the correct size and volume for the studied indoor space.

When measurements of physical quantities are performed not only by software calculation but also in the field, ISO 7726 should be taken into account because it describes procedures and different methods for measuring different physical parameters.

In the present work, the type of environment was homogenous and steady-state which has been verified by the compliance with the standard ISO 7726 (1998). The verification of the applicability of the standard ISO 7726 in the current research was performed for humidity, air temperature, mean radiant temperature and air velocity with the exception of human radiation which was not measured. According to ISO 7726 real measurements of physical quantities should be performed and then compared with values obtained by CFD simulations.

Thermal comfort and local thermal discomfort were assessed according to the initial goals as the initial proposed objectives were almost all achieved. Thermal local discomfort due to draught was not evaluated. The causes of local thermal discomfort evaluated with the help of Design Builder software to this type of analysis were: vertical air temperature difference, warm or cold floor and finally radiant temperature asymmetries.

Nevertheless, a proper experimental campaign made «in situ» in order to obtain real values of every single physical factor that influences thermal comfort is recommended to posteriorly verify the accuracy of the final results of the performed simulations.

In the present work the value of 0.40 renovations per hour for natural ventilation was adopted as a minimum air change rate which is a value established based on health criteria according to REH.

Also, the experimental simulations considered the case of all doors closed and an opened window (10%). This value could have small variations in future studies also.

These specifications are another type of limitation of this work because simulations could have been performed with variation of this type of input data in order to study the variability of the air change rate within an indoor space which is a possible future research.

5. FUTURE WORK AND PERSPECTIVES

Natural ventilation is a simple case of study caused by wind and buoyancy forces as is the study case presented in this paper.

In a future study, another types of ventilation system could be addressed and analysed with a more complex case of simulation or eventually considering another different boundary conditions such as windows closed and doors opened or windows closed and doors closed.

Also, real measurements could be performed using the tracer gas method to determine air change rates, with tracer gas such as carbon dioxide (CO_2) or sulphur hexafluoride (SF_6).

After the measurements campaign *in situ*, it would be possible then to verify if the minimum required value of ventilation rate of 0.40 hourly renewals is reached or outlined and CFD simulations could be performed with these new real values.

In addition, CFD analysis can be extended to the entire floor rather than just analysing only one room to understand the flow changes between the various adjacent rooms.

In «situ» measurements, when compared with the values obtained by the software, may serve as a guarantee of a good reliability in the results extracted from the software.

For future investigation, the real measured ventilation rates *in situ* could be used on the CFD software to analyse the output data.

This type of analysis could be performed in a heterogenous and transient environment with the guidance of ISO 7726 (1998) different from the one studied on this paper.

Adjusting ventilation rates to real rate of occupancy can possibly have a great impact on the final energy's building consumption, which is more noticeable for service buildings as this study case which presents a highly variable pattern during the working period.

In the initial research of the study, the presented value of 40% for energy consumption worldwide related to the building sector is a significant number for further investigation.

Also, as energy is very actual and a current topic of discussion nowadays that initial value could be somehow confirmed by a future study.

This study did not considered an evaluation of the final energy consumption of the building. In a future research it could be performed an evaluation of the energetic balance of the entire building in order to obtain the real annual energy consumption values.

After that, studying indoor air quality and air change rates could be addressed correlating both topics.