A new test room for indoor environmental quality analysis

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Abstract. A new test room for IEQ analysis is under construction at the University of Padova. The CORE-CARE Laboratory (COntrolled Room for building Environment Comfort Assessment and subjective human Response Evaluation) is a test room of about 18 m^2 equipped with radiant systems on the ceiling, on the floor and on all the walls, except for the area of the windows. Each surface is independently controlled, thus enabling to reproduce a room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. The room is also provided with fresh air with controlled flow rate, supply temperature and relative humidity. At first the test room will be used to evaluate, through questionnaires, psychological and productivity tests, the acceptability of defined factors of local thermal discomfort. Not only thermal comfort will be studied, but also perceived air quality, acoustic and lighting aspects will be considered as well. In the present work, the first steps of the set-up of the test room are presented, from the design phase to the building up, along with a brief presentation of the future research activities.

1 Introduction

Indoor Environmental Quality (IEQ) includes different aspects: thermal comfort, indoor air quality, lighting and acoustics [1]. A considerable amount of literature in the last few decades has recognized the significance of IEQ in response to the increasing desire to enhance human well-being [2]. As a consequence, many researchers are facing the challenge to understand how the different IEQ factors affect human perception of the built environment, health and productivity [3,4]. The research activities can be divided in experimental studies and field studies. In the first case the research is carried out in a test chamber or in a space with controlled environmental parameters and the test panel components are recruited to assess their perceptions of the environment, perform tests and measure their physiological parameters. In the second case the research is carried out in real buildings and post occupancy evaluation is used as main approach.

The widest variety of test chambers for the study of thermal comfort of people in buildings can be found at the International Centre for Indoor Environment and Energy, Technical University of Denmark. In 2004 this centre had at its disposal 12 spaces for studying indoor environments and the impact on human comfort, health, productivity at moderate energy demands [5]. The three oldest climate chambers date back to the 70ies and 80ies. In one of these chambers [6] Fanger studied the limits for asymmetric thermal radiation due to a heated ceiling [7], a cooled ceiling, a heated wall and a cooled wall [8]. The temperature of the surfaces of the room could not be controlled; in the first case a suspended light ceiling was used with an electrically heated plastic foil to control its surface temperature, while in the other cases water-based radiant panels were set inside the room. In 2001 three new indoor environmental chambers for tests with subjects were built, along with a laboratory for the study of air movement in spaces and around humans, and five offices were arranged for field experiments under controlled environmental conditions. The three chambers have the same dimensions (5.4 m × 4.2 m × 2.5 m) and resemble real office spaces, also thanks to the presence of three windows (1.0 m × 1.0 m) facing the daylit hall in which they are placed. The temperature of the surfaces of the chambers cannot be controlled, since they are simply made of steel plate elements with a core of polyurethane foam. The air temperature inside the rooms can be controlled from 10 to 40°C. Different ventilation principles are used in the three chambers (mixing, displacement and piston) with a volume flow rate which can be adjusted continuously from 12 to 170 l/s (24 to 340 l/s in one of the room) and with an outdoor air ratio ranging from 0 to 100%. The three climate chambers were designed for research on thermal comfort, air quality, health and productivity and are suitable also for long-term exposures.

Another well-known facility is the test room of the Department of Architecture Building and Planning at Eindhoven University of Technology [9]. The room dimensions (3.6 m × 5.4 m × 2.7 m) are representative of an office. The temperature of each surface can be individually controlled in the range 11-35°C, allowing to study the effects of radiant temperature asymmetries. A modular system composed of extruded anodized aluminum profiles is used for the surfaces, making the response time short. Two ventilation principles can be applied to the test room (mixing ventilation and displacement ventilation), with a flow rate which can be continuously adjusted up to 170 l/s. The temperature range of the inlet air is 9-45°C and the relative humidity

in the room can be controlled from 30 to 80%. The test room was designed to adequately assess thermal comfort under non-uniform and transient environmental conditions both from a global and local point of view, analyzing also the productivity of test subjects and the differences in physiological responses between males and females [10,11].
In 2016 a new climate room was built at the Technical University of Dresden, as part of the Combined Energy Lab 2.0 [12]. The chamber dimensions are 5.0 m × 4.0 m, with a height of 2.5 m. All the surfaces of the room are made of modular elements with the dimensions of 1 m × 2.5 m. The modules are made of a water-based capillary system placed on a metal plate and the external side is insulated with a polyurethane foam. Temperature sensors are placed on the metal plate to measure the surface temperature. Each of the 18 modules of the walls is made of 3 segments which can be independently controlled in temperature, while the 16 modules of the ceiling and of the floor are made of one segment. Thanks to this kind of modules, the system has a very low response time and a great flexibility. The supply water temperature of each capillary segment is controlled by a three-way valve, which mixes the hot and cold water mass flows provided by the hot and cold distribution networks. The surface temperatures of each segment can be regulated in a range from 10°C to 50°C with a heating/cooling rate up to 4 K/min. The climate room is connected to a ventilation and air conditioning systems with a maximum flow rate of 600 m^3/h, which corresponds to an air change of 12 h^{-1}. The air temperature can be regulated in a range from 10°C to 35°C and the air humidity from 20% up to 90%. The air supply and extraction are provided through 4 grids placed in 2 opposite walls of the room. A detailed description of the chamber and the first investigations can be found in [13].
The increased interest which has been paid in IEQ and especially in thermal comfort moved the group BETA-Lab of the Department of Industrial Engineering of the University of Padova to decide to build up a test room to make future analyses on well-being of people, perception of the indoor environment and productivity together with the Department of Psychology. In the present work, the first steps of the set-up of the new test room are presented, from the design phase to the building up, along with a brief presentation of the future research activities.

2 Design of the test room

2.1. General description

The CORE-CARE Laboratory (COntrolled Room for building Environment Comfort Assessment and subjective human Response Evaluation) is currently under construction and should start operating in the first months of 2019. The basic idea behind the test room is to investigate different combinations of indoor parameters to check their influence on the perception of the environment by panels of users. For doing this, it has been decided to keep the environment as much neutral as possible so that it looks like a real office rather than a test facility.
The spaces available for the laboratory were two rooms at the 3rd floor of the Headquarter V of the Department of Industrial Engineering at the University of Padova (Figure 1). The external wall of the test room is East-Southeast oriented. There is no building in front of the test room which can shade the building or can inhibit the external view.

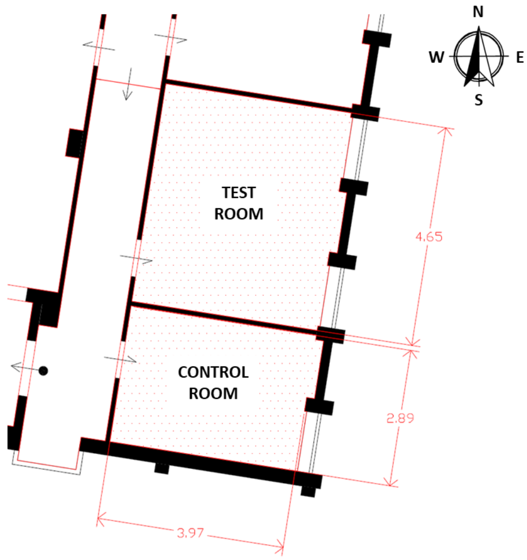

Fig. 1. Planimetry of the test room and the adjoining control room.

The test room, of about 18 m^2 and 3 m height, is equipped with radiant systems on all its surfaces. Dry radiant systems have been chosen for the ceiling and the walls (excluded the area of the windows), while for the floor a radiant system with quartzite and resin screed has been preferred, in order to have a finished surface without the need of a covering. The supply water temperature of each surface is independently controlled thus enabling to reproduce a real room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. The room is also provided with fresh air with controlled flow rate; air can be controlled in temperature in winter time and in temperature and relative humidity in summer time.
The other room (named control room) is used to house the technical equipment, which consists mainly in:

- 2 primary loops, one for heating and one for cooling;
- 6 secondary loops (one for each surface) with 6 mixing and pumping units;
- 3 inertial tanks (heating loop, cooling loop and chiller loop);
- 1 air handling unit and related air ducts;
- pumps and valves for each circuit;
- control system.

The water of the heating loop is heated in the tank by electrical resistances, while cooling is provided by a chiller placed on the roof of the building. Glycol antifreeze is used in the chiller loop, which is separated

from the cooling loop by means of a plate heat exchanger.
The test room is equipped with windows; therefore the tests will be performed in heating or cooling conditions according to the outdoor environment, i.e. tests will be performed with systems in heating operating conditions in winter and in cooling conditions in summer. New windows have been installed on the external dry-wall to avoid problems during the tests, since the pre-existing windows presented low thermal and acoustical performances. The old windows remained on the external side of the wall and the new ones have been installed on the internal side. Between the two windows new Venetian blinds will be installed, ready to be electrically driven and eventually controlled on the basis of the light illuminance inside the room.

2.2 Radiant surfaces

The design of the radiant surfaces has been be the most critical and challenging phase of the entire project. Dry systems were chosen (except for the floor), and in the case of the external wall the presence of the windows made particularly difficult to find in the market panels with a size which fits the available space. Moreover, it was not possible to choose the same manufacturer for the modules of all the walls since the material was donated. This implicated to deal with 6 different systems which had different pipe diameters (the pipes inside this kind of panels are not standardized), different connectors, different dimensions of the panels, different layout of the structure behind the panels and different laying rules. In this section the layout of the panels and of the hydronic connections of each surface of the room is presented.
As regards the floor, a radiant system with quartzite and resin screed has been chosen. The distinctive trait of this system is the very low thickness of the screed above the clew, which is only 3 mm. Since the dry walls must be installed after the floor, a reduced available surface has been considered for the position of the pipes. The resulting thermally active surface is 17.2 m^2 with 5 loops. The manifold has been placed in the control room because in the test room there was no space available on the walls. The layout of the floor radiant system can be seen in Figure 2.
As regards the ceiling, a system made of plasterboard panels coupled with insulation and aluminum plate diffusers has been chosen. The panels are to be screwed on a structure of metal profiles hang to the ceiling and can be drilled in some marked position for placing spot lights with a diameter of maximum 10 cm. The position of the panels has been studied to allow the positioning of 2 linear slot diffusers near the North wall. The thermally active surface is about 13 m^2, i.e. the 75% of the surface of the ceiling (considering the surface of the new room). The panels are supplied by two loops and the related manifold is placed on the ceiling of the control room. The layout of the ceiling radiant system can be seen in Figure 3.

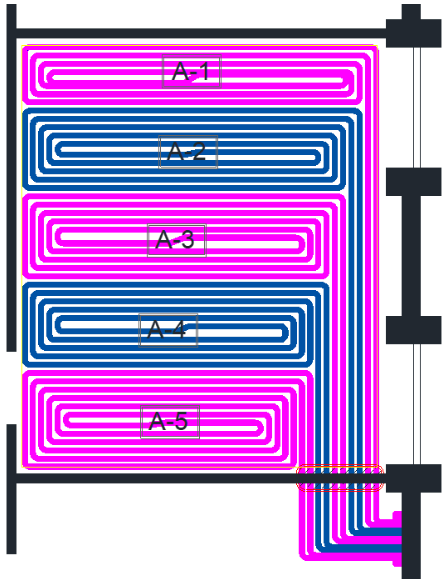

Fig. 2. Layout of the radiant floor system.

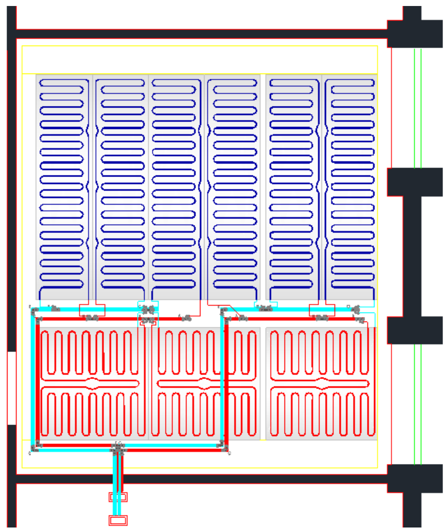

Fig. 3. Layout of the radiant ceiling system.

Dry radiant panels have been used also for the walls of the test room. The dimensions of the panels and the resulting active surfaces are shown in Table 1.

Tab. 1. Active surface of the walls.

Surface	Panel dimensions [mm]	Number of panels	Active surface [m^2]
North wall	1200 x 2000	3	7.20
East wall	600 x 2000 1000 x 1200	3 2	6.00
South wall	625 x 2000	6	7.50
West wall	625 x 2000	4	5.00

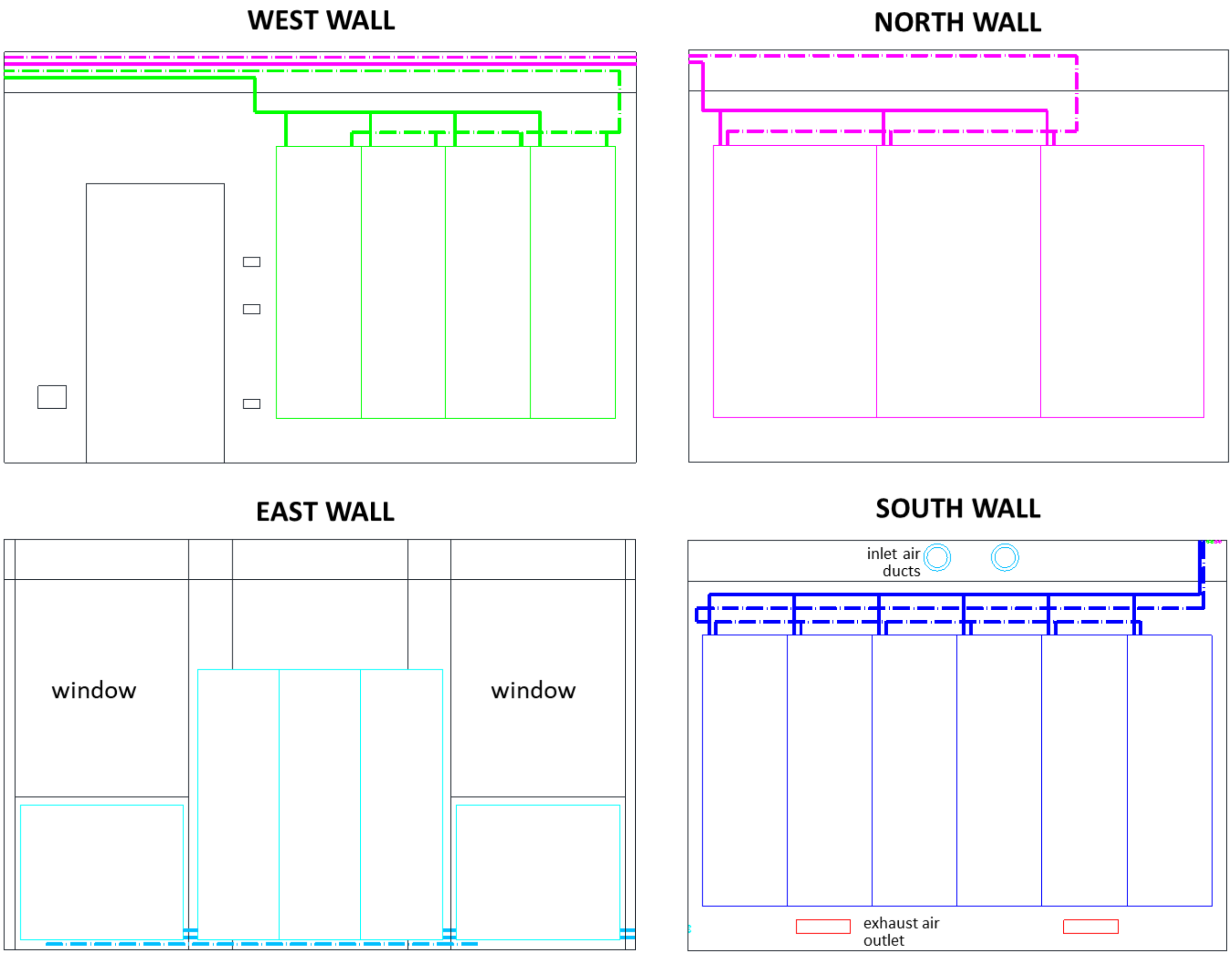

Fig. 4. Layout and hydronic connections of the radiant panels on the walls.

The positions of the panels on each wall, which can be seen in Figure 4, has been defined taking into account the space needed by the exhaust air grilles and by the new electrical system (light switches, wall sockets, data network access points, etc). The layout of the hydronic connections is also shown: for each wall an independent circuit has been realized using pipes with an external diameter of 20 mm which connect the radiant panels according to the Tichelmann system. The connections have been realized from the upper side of the modules, except for the modules of the external wall, which have been connected from the lower side, with the pipes placed in the recess behind the dry wall.

The panels of the South and West walls are not pre-insulated, thus mineral wool insulation (5 cm thick) has been placed behind them. Mineral wool has been also used to fill the recess behind the external dry wall, between the vapor barrier on the rear part of the radiant panels and the vapor barrier placed on the internal side of the concrete wall.

Usual design conditions of the radiant systems cannot be defined in a test room like this, since there is no heating or cooling load to be supplied. As a matter of fact, many combinations of temperature for the radiant surfaces are possible, with some of the surfaces heated and some cooled at the same time and other surfaces at neutral temperature. Hence the boundary conditions have to be set for checking all possible tests which can be performed for heating and cooling, looking at minimum and maximum allowable temperature which in case can be exceeded. For winter investigations, a maximum surface temperature of 40°C has been considered, except the floor surface which was considered at 29°C. For summer investigations, a minimum surface temperature of 16°C has been considered.

2.3 Hydronic system

The radiant panels of the 6 surfaces of the test room are supplied by means of 6 secondary loops, each equipped with its own mixing and pumping unit. Upstream 4 ball valves allow to manually commute between heating and cooling. The 2 primary loops are provided with modular manifolds made of reinforced polyamide and equipped with micrometric flow regulator and flow-rate meter for each circuit. Not only the radiant panels, but also the air handling unit is supplied by the manifolds.

The heating loop has a tank of 200 litres with 3.6 kW of electric heaters. The electrical resistance has been chosen to allow a short time of pre-heating before the start of the tests.

The cooling loop has a tank of 100 litres and is de-coupled from the chiller loop by means of a plate heat exchanger. The chiller loop is 80 m long and has an inertial tank of 50 litres, for a total volume of 90 litres. This loop is treated with a dosage of 30% of an inhibited

antifreeze, formulated to help control corrosion and to provide frost protection down to -15°C.
The primary and secondary circuits, included the hot and the cold tanks, have a volume of 375 litres and must be treated with a dosage of 1% of inhibitor, which provides protection against limescale and corrosion, and a dosage of 0.3% of sanitizer and biocide, which prevents the development of bacteria and fungi and their associated problems.
Expansion vessels, safety valves, air purge valves and filters complete the system. About 20 cockpits for thermometer probes (Pt500 will be used) will be installed for properly monitoring the water temperatures of the radiant circuits and in other important points of the hydronic system.

2.4 Aeraulic system

The test room is provided with fresh air with controlled flow rate, supply temperature and relative humidity. The following operation modalities are possible for the chosen air handling unit:

- fresh air ventilation;
- winter integration;
- dehumidification and/or summer integration;
- free cooling or free heating.

The AHU uses the outside air only, it is equipped with a high-efficiency counter-current heat exchanger (about 90%) for heat recovery from exhaust air and with a by-pass connection for free-cooling, controlled by an NTC probe placed in the outdoor air intake duct. It ensures summer dehumidification and can also integrate heating and cooling, operating as a heat pump. It consists of three separate modules, two fan units and one recovery/handling unit, which can be installed close together or in different positions, depending on the space availability.
The selected air handling unit can provide an air flow rate from 80 to 200 m^3/h to the test room, ensuring an air change from 1.7 h^{-1} to 4.2 h^{-1}. It is independently controlled by a TH controller user terminal but can also be controlled by an external device.
Silencers are installed between the AHU and the test room to reduce noise transmission. The distribution of air is done through flexible insulated air ducts with diameters of 160 mm and 125 mm and distribution boxes. Two linear slot diffusers (800x100 mm) equipped with air shutters and placed on the ceiling are used for supply air, while two grilles (400x400 mm) are placed on the lower part of the opposite wall for exhaust air extraction. The dimensions of the diffusers and the grilles ensure low air velocity near the inlet and extraction areas in the test room.

3 Building up of the test room

A view of the room before starting the works can be seen in Figure 5. After the clear out of the room, the first work to do was the radiant floor system, followed by the radiant walls and finally the radiant ceiling. Particular attention was given to the external wall, since the hydronic connections were placed behind the panels because the space under the windows was limited. A vapor barrier was placed on the external existing concrete wall, then all the space behind the dry wall was filled with mineral wool insulation and another vapor barrier was placed immediately behind the radiant panels. The space behind the radiant panels installed on the internal walls was also filled with mineral wool insulation, except the panels of the North wall which were pre-insulated.
A view of the test room and of the control room during the works are shown in Figure 6 and Figure 7 respectively. The works will be completed in April 2019.

Fig. 5. View of the room before starting the works.

Fig. 6. View of the test room during the works.

Fig. 7. View of the control room during the works.

4 Future research activities

The first activity which will be carried out will be the starting up of the system and the evaluation of the time needed to reach steady-state conditions as well as how these are maintained over the time. Measurements by infrared camera will be taken with many combinations of surface temperatures in order to check how the different surface temperatures affect indoor operative temperature.

The set-up of the room will include measurements of air velocity, temperature and turbulence under different flow rates in order to avoid draft risk problems in the rooms.
At the same time a correlation between supply temperature of the water and surface temperature will be carried out. A suitable number of thermocouples will be installed in active and passive surfaces of each wall, as well as inner surface of windows. The view factor model presented in [14] will be considered to calculate the view factors between the human body and the different surfaces in various positions inside the room. The measured mean radiant temperature with and without occupants will be compared to the one calculated through the measured surface temperature and the calculated view factors.
At the same time a model for the hydronic circuit will be developed in order to find the best strategies to control the temperatures of the warm and cold water in the two tanks, as well as the proper mixing temperatures to supply the water in all the circuits. Also the AHU operation will be tested and tuned as a function of the different external conditions (temperature and relative humidity).
Once tuned the control of the room, the work including panels of occupants will start. At first the test room will be used to evaluate, by means of questionnaires, psychological and productivity tests, the acceptability of defined factors of local thermal discomfort and their influence on human productivity. As regards thermal comfort, an argument which needs in-depth investigations is surely the radiant temperature asymmetry. In particular the analysis on comfort and productivity of people under heated ceiling deserves a prominent attention.
The idea is to study the radiant asymmetry of a room with warm ceiling and one or more cold walls or cold floor, along with the acceptability for people of a possible discomfort. For this purpose, a working space with 2-4 people should be reproduced in the test room. Many combinations of surface temperature can be studied, considering also the possibility to control the supply air of the ventilation system. The experimental investigations with test subjects will be performed considering realistic combination of the surface temperatures of a typical room in a building during the winter, e.g. two cold walls or the cold floor and one cold wall. The possibility to plan the activities as complementary studies to the ones carried out in other research centres will be considered.
In the future other works are planned looking at integrated methods for multi-parameter analysis of global comfort & IEQ in office buildings. As a matter of fact, the studies of the characterizing parameters and of the control methods for the optimization of comfort in building environments are currently mainly focused on the aspects related to thermal comfort and IEQ. Many other aspects and potential correlations, though not neglected, are not yet fully investigated and can be hence currently the subject of in-depth studies. It is the case of the acoustic and lighting environment, yet both are directly dependent on the energy management strategies of buildings. The noise level generated inside a building environment is mainly due to the operation and characteristics of the service equipment, mainly HVAC and mechanical ventilation systems. Natural and artificial lighting are increasingly connected to the managing the contribution of solar radiation through the transparent components of the building envelope. The purpose of the research program is to deepen the interactions between different parameters on global comfort, especially for offices and commercial buildings. To do this, the development of specific methods for analysing the subjective response is expected from the current standardised procedures used for the analysis of comfort in thermally controlled environments. These methods will be developed taking into account the most recent advancements in dialogic psychology, for the analysis of the subjective response of users, and the assessment of productivity related to the daily variation of comfort indicators, following the implementation of energy saving strategies.

5 Conclusions

Indoor environmental quality has gained an increasing interest in response to the increasing desire to enhance human well-being. Thus more investigations employing test subjects should be carried out in spaces with controlled environmental parameters.
After a brief presentation of the most important characteristics of some existing test chambers, the first steps of the set-up of a novel test room are presented in detail, from the design phase to the building up. The most important feature of this new test room is the possibility to independently control the temperature of each surface (floor, ceiling and walls); this enables to reproduce a room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. Moreover, the test room is located in an office building, it is provided with windows and it has been kept as much neutral as possible, so that it looks like a real office rather than a test facility.
Not only thermal aspects will be investigated in the new test room, but also the illuminance level and the acoustics in the indoor environment will be taken into account. The ultimate challenge of the future research activities is to understand how the different IEQ parameters and their interactions affect human perception of the built environment and productivity.

The project of the test room has been realized thanks to the collaboration with 18 companies which donated most of the materials needed for the construction. Among the companies, the Consortium Q-Rad (Italian consortium of radiant systems producers) played an important role. The project is in part financed by TWINNING, a funding program supplied by the Department of Industrial Engineering.

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