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Extended summary

Thermal comfort in new insulated buildings: impact of glazed windows and heating systems.

Curriculum: Architecture, Costructions and Structures

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Abstract. This summary presents the results of an experimental and numerical analysis on the effect during winter of cold windows and two types of low temperature heating systems, radiator and floor heating, on thermal comfort in well insulated buildings. The main focus was to assess the influence of window geometry and an intermittent control strategy of the heating system on indoor thermal comfort and energy consumption. For this purpose an experimental campaign in two real case studies and in a test room under controlled conditions was set up. Furthermore, dynamic whole building energy simulation was performed combined with a computational fluid dynamics (CFD) study. The experimental results showed that low temperature radiators provide an indoor comfort level higher than floor heating radiant system and that there is a thermal discomfort zone near a standard window, of 1.2m. Both the CFD model and transient thermal model was validated with experimental measurements and then used in the investigation. The CFD analysis showed that the influence of Window to Wall Ratio (WWR) on thermal comfort is considerable. The results of the transient thermal model demonstrated that the thermal comfort difference between radiators and floor heating systems is negligible. However, low temperature radiators, with an intermittent control strategy, save between 20% and 25% energy when compared with the use of floor heating systems.

Keywords. Energy consumption, windows, low temperature heating , MRT, thermal comfort.

1 Introduction and objectives

The primary objective of new buildings is to provide shelter, space, and comfort for the people that live, work, and interact in them. The energy related issues in buildings are only secondary factors and it is important to check whether a comfortable indoor environment is achieved without increasing energy use.

Indoor thermal climate characteristics have been analyzed by a number of researchers, such as Olesen et al. [1], [2]. who performed measurements in a room heated by different methods and studied radiant heating systems. Other researchers investigated low temperature heating systems and the local thermal discomfort near cold or hot surfaces. Gan [3] analyzed the effect of glazing on the mean radiant temperature and thermal comfort in a room. They concluded that using a radiator under a window reduces local thermal discomfort but the hot radiator itself creates problems of overheating. Several recent study analyze the influence of cold or hot windows in modern insulated buildings heated or cooled by radiant heating systems. The discomfort penetration depth caused by windows have been analyzed [4]. During this study the authors looked at: window surface temperatures, window geometries and solar radiation. The study identified several possible window comfort ratings for winter and summer. Full scale experimental campaigns were conducted by [5],[6] to analyze the indoor thermal comfort obtained by a radiant ceiling coupled with their environment (window, wall, internal loads). Laboratory test results showed that the influence of surface temperatures inside the room is considerable.

Energy consumption analysis was performed by Hasan et al. [7]. Experimental and numerical investigations were performed about a new combined low temperature water heating system that included radiators in a room and floor heating in bathrooms. The results indicated that using low temperature radiators the ambient was in an acceptable temperature range and that there was only a small vertical temperature difference that did not produce any significant thermal discomfort. The results showed also that the heating energy demand for the proposed low temperature system is in the same range as that required by other conventional systems.

The objective of this research is the study of indoor thermal comfort in modern well insulated building, using the Predicted Mean Vote (PMV) method. The main thermal comfort problems which may occur in these buildings are large variation in the room temperature, due to changes in internal loads, and radiation problems caused by cold windows. Therefore the main focuses are to quantify the extent of thermal discomfort caused by the window under a winter climatic condition and analyze the difference, in terms of thermal comfort and energy consumption, between two types of low temperature heating systems(radiator and floor radiant systems). For this purpose an experimental campaign in two real case studies and in a test room under controlled conditions were set up. Simulation with computational fluid dynamic (CFD) models, validated with experimental test room results, has been conducted to assess the influence of the Window to Wall Ratio (WWR) on indoor thermal comfort. Simulation with transient thermal model, validated with experimental measurements in the real buildings, has been conducted to predict thermal comfort and energy consumption with the use of the two different low temperature heating systems.

Figure 1 : View of case studies : new building of Engineering, wooden frame house and climatic chamber.

2 Case studies and experimental facilities

Experimental measurements were taken in two real buildings located near Ancona (Latitude: 43°37’ N, Longitude: 13°31’E, Altitude: 163m.s.l.m). The first case study, the new building of Faculty of Engineering of the “Università Politecnica delle Marche”, was taken into account due to its unobstructed double glazed north oriented façade (Fig.1). On the opposite of the glazed façade there is a study space; thermal sensation of the occupants may be affected by the radiation problems caused by cold glazed surface. The study space was monitored to obtain thermal comfort in two points at increasing distance from the glazed façade .The first measuring point was close to the glazed surface, while the second point was close to opposite opaque surface. The experimental investigation was carried out from the 25th of February 2010 to the 15th of March 2010. The second case study, a wooden framed house, consisted of a well insulated building envelope and heated by a floor heating system (Fig. 1,b). The heating system was operated intermittently to avoid overheating problems and to save energy. The heating system was turned on from 9.30 a.m. to 14:00 p.m. and the room was occupied during the afternoon hours. A room of the building, equipped with a standard double glazed window, was monitored in order to assess thermal comfort while the building was occupied. The experimental investigation was carried out from the 24th of February 2011 until the 3rd of March 2011. Both experimental set ups were composed of a meteorological station and one or two indoor microclimatic stations. The meteorological stations recorded: air temperature, wind velocity, wind direction, relative humidity and horizontal global solar radiation. The indoor stations recorded: internal surface temperatures, indoor air velocity and temperature, black-globe temperature and relative humidity. The experimental data enable us to evaluate Mean Radiant Temperature using the UNI EN ISO 7726 [8] method and PMV index using the UNI EN ISO 7730 [9] method.

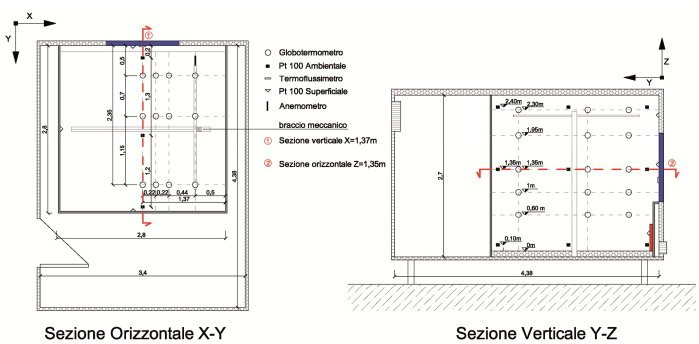

Figure 2 : Scheme of Three - dimensional mapping of indoor microclimatic conditions.

Analysis of the wintertime discomfort caused by windows in a room heated by low temperature heating systems can be a delicate issue. Therefore an experimental investigation under controlled conditions is mandatory. For this purpose a full scale test room was equipped with the electric floor heating systems and low temperature radiator (Fig. 1 – Fig. 2)

The climatic chamber was equipped with adiabatic walls and a standard size window. It was heated to maintain a mean air temperature of 20°C. Three – dimensional mapping of globe temperature, air temperature and air velocity was carried out under steady state conditions. The experimental data was used to evaluate the thermal comfort using the PMV method and to set up boundary conditions necessary for the CFD study.

3 Simulation methods

Simulation with computational fluid dynamic (CFD) model, validated against the experimental test room results, has been conducted to assess the influence of Window To Wall Ratio (WWR) on indoor thermal comfort. The CFD model was based on the description of the experimental test room. The airflow pattern and temperature distribution in the facility is governed by the conservation laws of mass, momentum and energy. The flow is assumed to be steady state, three-dimensional, incompressible and turbulent. The buoyancy effect is invoked in the momentum equation, k and ε. The numerical model reproduced an example office room of 2.74 m long, 2.76 m wide and 2.6 m high in winter conditions to demonstrate the importance of the mean radiant temperature on the thermal environment. In one of the walls there is a double-glazed window of 1.2 m wide and 1.2 m high and with a U-value of 2 W/m^2. It is assumed that the room is at an isothermal condition with the wall at a winter design temperature of 20ºC. The design outdoor air temperature is -2ºC.

Simulation with transient thermal modeling, validated with experimental measurements in the real buildings, has been conducted to predict thermal comfort and energy consumption with the use of the two different low temperature heating systems. The performance of the building and the HVAC systems are evaluated using the Energy Plus 6.0 program This is a whole-building dynamic simulation program with climate processor. The program can be used for the simultaneous performance assessments of all issues fundamental to building design: shape, envelope, glazing, HVAC systems, controls, light, indoor air quality, comfort, energy consumption, etc. The numerical model was based on the geometric and thermal characteristics of the monitored room of the wooden framed house. The room was 4.65m long and 3 m wide with a medium height of 3m. The exterior wall had a U-value of 0.22 W/m^2 and the windows had a U – value of 2 W/m^2. The floor heating system was modeled using the "low temperature radiant systems" component, while low temperature radiators were modeled using the "baseboards with convection and radiation" component. To simplify the modeling both heating systems were set as electric.

4 Results

4.1 Experimental results

The experimental data from the new building of Faculty of Engineering, shows the mean radiant temperature near the widow was lower than the MRT near the opaque surface although the air temperate had the same value in this two measurement points . The experimental results from a winter sunny day demonstrate that, with an outside temperature of about 15°C, there was no difference between the MRT recorded near windows and that recorded near the opaque surface. Instead the experimental results from a winter cloudy day demonstrate that, with an outside temperature of about 2°C and an interior glass surface temperature of about 13°C, the difference between the two MRTs was higher than 3°C. This means that there is a big difference, in terms of thermal comfort, between the two measurements points.

The experimental results from the wooden frame house demonstrate that the floor heating system did not ensure thermal comfort during its operation time. Moreover changes in internal loads were the cause of uncontrolled variation in the room air temperature and PMV.

Test room experimental results were presented in terms of horizontal mapping of mean radiant temperature (Fig. 3) and PMV, and vertical section of air temperature and velocity.

Results shows that the radiant temperature patterns due to the cold window are deflected upwards by the radiant heat exchange from the low temperature radiator. The zone with low value of mean radiant temperature was about 0.5m in the room heated by radiators. While the same zone measured about 1.2m in the room heated by floor radiant system. This indicates that the distance of thermal discomfort is reduced by the radiators and thus more comfortable space would be available for occupancy. Low temperature radiator ensure also air temperature uniformity as floor radiant systems. The air velocity was lower than 0.05m/s with both heating systems and there was no local thermal discomfort. Experimental results showed also that the area of thermal discomfort increases with window size.

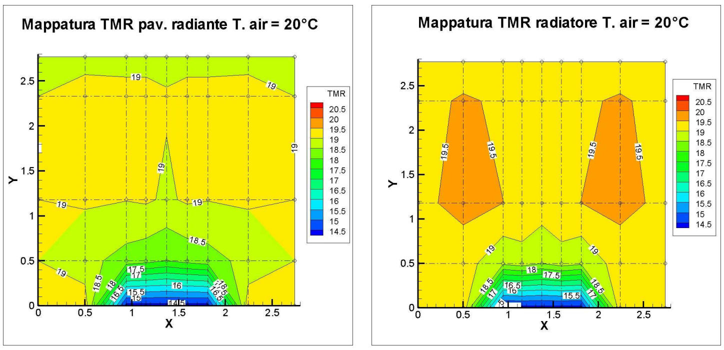

Figure 3 : MRT horizontal mapping of test room heated by low temperature radiator and floor heating systems.

4.2 Numerical results

CFD simulation results demonstrate that in a room equipped with a standard double glazed window (WWR = 0.2) the maximum distance of thermal discomfort is reduced by the radiator. In this case more comfortable space was available using a low temperature radiator than using a floor heating system. When the same radiator was installed under a wider (WWR = 0.67) double-glazed window the cold discomfort near the window was completely eliminated, but there was a larger area of hot discomfort from the radiator. In this case more comfortable space was available using floor heating systems than using radiators.

Generally when the mean surface temperature of the radiator was under 40°C there was not discomfort due to the high temperature of the radiator. The model validation is important to ensure adequate results from the CFD simulations. The validation was focused on the comparison of air temperature and mean radiant temperature. The comparisons between the experimental and the numerical data confirm the validity of the numerical model used in the CFD simulation.

The transient building thermal software predicts surface temperatures, room air temperature and MRT in a room heated by floor radiant systems or radiators. These results enable us to assess the differences, in terms of hours of thermal comfort and energy consumption during the heating season, between the two heating systems using different strategy of occupation of the room and operation of the heating systems. The results show that using a correct intermittent control strategy, radiators ensure the same thermal comfort hours when compared with floor heating systems. The best intermittent strategy for floor heating systems in a residential building , occupied only in the evening hours, was to turn on the system during the morning. While the best intermittent strategy for radiators in a residential building was to turn the systems on during the occupation time. However the amount of energy used by radiators was about 20%- 25% lower than the amount of energy used by floor heating systems.

The simulation model was compared with the experimental measurements by using the same climatic data from the measurements as inputs. The results of the validation demonstrate that the proposed model provided an acceptable accuracy.

5 Conclusion

This summary presents the results of an experimental and numerical analysis on the effect during winter of cold windows and two types of low temperature heating systems, radiator and floor heating, on thermal comfort in well insulated buildings. The experimental results showed that there is a large difference, in terms of thermal comfort, between a zone close to the window and a zone close to an opaque surface. Furthermore, it was observed that the floor heating system did not ensure thermal comfort during its operation time.

The comparisons between the experimental and the numerical data confirm the validity of the numerical models used for the investigation.

The CFD analysis showed that the influence of the Window to Wall Ratio (WWR) on thermal comfort is considerable. The results of transient thermal model demonstrated that thermal comfort the difference between radiators and floor heating systems is negligible. However low temperature radiators, with an intermittent control strategy, save between 20% and 25% energy when compared to the use of floor heating systems. Therefore in well insulated buildings low temperature radiator perform well and are able to maintain the zones within the required comfort level.

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