DTU Library

IEA EBC Annex 59 - Possibilities, limitations and capacities of indoor terminal units

Kazanci, Ongun Berk; Olesen, Bjarne W.

Published in:
Energy Procedia

Link to article, DOI:
10.1016/j.egypro.2015.11.213

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 00 (2015) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

6th International Building Physics Conference, IBPC 2015

IEA EBC Annex 59 - Possibilities, limitations and capacities of indoor terminal units

Ongun B. Kazanci*, Bjarne W. Olesen

International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Nils Koppels Allé, Building 402, 2800 Kgs. Lyngby, Denmark

Abstract

Indoor terminal units can be defined as the building elements that use different heat transfer mechanisms and media to emit and remove heat or moisture from indoor spaces (e.g. hydronic radiant heating and cooling systems, fan-coil units, active beams). Indoor temperature and humidity fields depend on the chosen terminal units.
Terminal units differ in their capabilities of addressing sensible and latent loads, methods of heat emission or removal, maximum heating and cooling capacities, medium of energy distribution, and local or total volume conditioning.
In the present study, operation characteristics, possibilities and limitations of different terminal units were specified. Considered terminal units were radiant heating and cooling systems, all-air systems (mixing, displacement, and personalized ventilation), passive and active beams. The results were summarized in a table, which aims at providing a reference for terminal unit selection during the design phases of HVAC systems.

Keywords: Indoor terminal unit; temperature and humidity field; radiant heating and cooling; ventilation; passive and active beams

1. Introduction

Indoor terminal units are active building components that emit or remove heat and moisture to indoor spaces. These indoor terminals mainly rely on convection (natural or forced), radiation or both. A recent research project from International Energy Agency (IEA), Energy in Buildings and Communities (EBC) Program [1], Annex 59 –

* Corresponding author. Tel.: +45 50281327; fax: +45 45932166.
E-mail address: onka@byg.dtu.dk

1876-6102

High Temperature Cooling and Low Temperature Heating in Buildings [2] is studying the currently existing terminal units. A sub-group within the project, Subtask B – Indoor temperature/humidity field and terminal units, is aiming to summarize the indoor heat and moisture sources and the current methods to address them. A further goal of the project is to provide improvement suggestions to the currently existing terminal units and HVAC systems.

This paper summarizes the characteristics of the chosen terminal units (radiant systems, mixing, displacement, and personalized ventilation, passive and active beams) and it aims to function as a simple and reliable reference tool for these units. Possibilities (heating, cooling, ventilation, humidification and dehumidification of indoor air), method (heat transfer mechanism) of heat emission and removal from the indoor space, heating and cooling capacities, and the medium of energy distribution are specified for different terminal units. It is assumed that the reader is familiar with the described systems and concepts. The given values are only intended to provide guidance, and the indicated capacities could vary depending on the application.

2. Hydronic radiant heating and cooling systems

A hydronic (water-based) radiant heating and cooling system refers to a system where the water is used as the heat carrier (medium of energy distribution) and more than half of the heat exchange with the conditioned space is by radiation [3]. It is possible to divide the radiant heating and cooling systems into three: radiant heating and cooling panels, pipes isolated from the main building structure (radiant surface systems), and pipes embedded in the main building structure (Thermally Active Building Systems, TABS) [3]. The heat carrier (water) circulating in the pipes has low temperatures in the heating and high temperatures in the cooling operation. In some TABS constructions (hollow core concrete decks) also air has been used as a heat carrier, and also electricity can be used in heating applications.

Floor, wall and ceilings can be used as surfaces that provide heating or cooling to the space. Hydronic radiant surface systems require a ventilation system to address the latent loads and to provide the ventilation rates required for indoor air quality concerns [3]. Radiant heating and cooling systems enable lower air flow rates than all-air systems where the entire heating and cooling loads are addressed by the ventilation system [4].

The heat emission or removal from the space is achieved by a combination of radiation and convection. Total heat exchange coefficients (combined convection and radiation) for floor heating, wall heating and ceiling heating are 11, 8, 6 W/m^2K, and for floor cooling, wall cooling and ceiling cooling are 7, 8, and 11 W/m^2K, respectively [3]. The radiant heat transfer coefficient can be used as a constant value of 5.5 W/m^2K, with an error of less than 4% [5]. The difference in the total heat transfer coefficients stems from the natural convection. An overview of natural convection coefficients is given in [6].

Based on the acceptable surface temperatures (comfort and dew-point concerns [3]), and assuming an operative temperature of 20°C and 26°C in the room for heating and cooling cases, the maximum heating and cooling capacities can be obtained. The maximum floor (occupied zone) heating and cooling capacities are 99 W/m^2 and 42 W/m^2, wall heating and cooling capacities are 160 W/m^2 and 72 W/m^2, and ceiling heating and cooling capacities are 42 W/m^2 and 99 W/m^2, respectively. In the perimeter zones of the floor, it is possible to obtain a maximum heating capacity of 165 W/m^2 [3]. Different studies [3,7,8] have shown that the cooling capacity of a floor cooling system increases above the given maximum capacity of 42 W/m^2 and may even exceed 100 W/m^2, when there is direct solar radiation on the floor.

Different construction types of radiant systems can be found in [3]. The design, test methods, control and operation principles of radiant panels are given in ISO 18566:2013 [9], while the design, dimensioning, installation and control principles of embedded radiant systems are given in ISO 11855:2012 [10].

3. All-air systems

Currently, there are eight commonly applied ventilation strategies in buildings. These strategies are mixing ventilation, displacement ventilation, personalized ventilation, hybrid air distribution, stratum ventilation, protected occupied zone ventilation, local exhaust ventilation, and piston ventilation [11]. For the ventilation systems, the main method of heat emission and removal is convection and the medium of energy distribution is air. A review of different airflow distribution and ventilation systems in buildings can be found in [11]. Mixing, displacement, and personalized ventilation systems are further described in this paper.

3.1. Mixing ventilation

Mixing ventilation (mixing room air distribution) intends to dilute the polluted and warm (or cool) room air with clean, cooler (or warmer) supply air. The aim is to achieve a uniform temperature and contaminant distribution in the occupied zone [12]. It is possible to heat or cool a space by mixing ventilation. It is also possible to provide dehumidified and conditioned outdoor air (fresh air). Typical supply air temperature range for heating and cooling is up to 34°C and down to 14°C, respectively [11]. The obtained heating and cooling effect will depend on the ventilation rate. Also in some countries, such as Denmark, the highest permissible supply air temperature is limited to 35°C by regulations [13]. It is not recommended to have a higher temperature difference than 10°C between the supply and room air to achieve proper mixing [12]. According to [14] a specific cooling load of 90 W/m^2 can be handled with mixing ventilation systems.

3.2. Displacement ventilation

Displacement ventilation (displacement room air distribution) is based on displacing the polluted room air with fresh air (conditioned outdoor air) [11]. The cool fresh air is supplied with low velocity (0.25-0.35 m/s [15]) at or near the floor, and the supplied air rises by the effects of momentum and buoyancy forces [11,15]. It is possible to provide cold, dehumidified and conditioned outdoor air with displacement ventilation. Although, it could be possible to provide warmer air than the room air with displacement ventilation (e.g. to heat an unoccupied room before the occupancy [16]) it is not common and it is not recommended due to the short-circuiting of the supply air. Typically, the supply air temperature can be down to 18°C [11]. The cooling load that a floor current displacement systemcan handle is 30-35 W/m^2 according to [15] and 50 W/m^2 according to [14].

3.3. Personalized ventilation

Other than the two mainly applied total volume air distribution principles (mixing and displacement air distribution), another air distribution strategy is personalized ventilation, and it aims at supplying the clean and cool air close to an occupant before it is mixed with the room air [12,17]. The most important advantage of personalized ventilation compared to the total volume conditioning systems is its potential to provide clean, cool and dry air at inhalation [17,18]. According to [11], the supply air temperature can be down to 20°C in cooling and up to 28°C in heating mode, but it should be noted that perceived air quality (PAQ) might be a problem with the increased supply air temperature [19,20] and ventilation effectiveness may decrease depending on the chosen air supply location and terminal.

The required ventilation rates can be calculated based on EN 15251:2007 [21] (this standard is currently under revision [22]), CR 1752:1998 [23], and ASHRAE 62.1-2013 [24].

4. Beams

Although these systems are known as chilled beams, a recent guidebook [25] refers to them as beams, and this terminology will also be used in this paper. Beams (passive and active) are room air recirculation devices that can heat or cool (sensible) a space using water as the energy distribution medium. Active beams can also provide conditioned primary air to a space (they are coupled to the main air-handling unit) [25]. Fresh air is delivered to the space by a decoupled ventilation system in passive beam applications.

Beams cannot directly humidify or dehumidify the room air since they operate in dry (non-condensing) conditions but it is possible to control the latent loads and to address the ventilation requirements with active beams [25]. The method of heat emission and removal from the space takes place mainly by convection.

4.1. Passive beams

The performance of passive beams relies on natural convection [25]. In passive beams, the medium of energy distribution from the plant is water. It is possible to heat and a cool space with passive beams but it is not possible to provide fresh air to the space. Although heating is possible with passive beams, in most applications, passive beams are used for cooling only and therefore a separate heating system should be used [25]. Also the ventilation needs should be addressed by a complementing system (e.g. by an air-handling unit) [25]. It is recommended to use passive chilled beams when the total sensible cooling load is up to 40-80 W/m^2 [26].

4.2. Active beams

The performance of active beams relies on convection that is caused by induction [25]. It is possible to heat, cool and provide fresh air to a space by active beams. In active beams, the medium of energy distribution is both air (fresh air, from the air-handling unit) and water from the heating or cooling plant. Active beams can typically be used when the total sensible cooling (air and water) load is less than 120 W/m^2 in comfort conditions [25,26]. The optimum operating range (for a good thermal comfort in sedentary type occupancy) is 60-80 W/m^2 [26]. For the heating case, the optimum operating range is a heating load of 25-35 W/m^2 and a maximum heating load of 50 W/m^2 [26]. The specific heating and cooling capacities of beams can be found in [26] expressed in W/m.

The testing and rating procedures of passive and active chilled beams are given in EN 14518:2005 [27] and in EN 15116:2008 [28], respectively.

5. Other systems

Another type of terminal units that can be used for heating and cooling of buildings is a fan-coil unit. Information regarding fan-coil units can be found in [6,14,29].

The descriptions, characteristics, operation principles and other information regarding other terminal units that were not a part of this paper (radiators, radiant tubes, convectors, etc.) can be found in [14,29].

6. Discussion and conclusion

Possibilities, limitations and characteristics (heating and cooling capacities, governing heat transfer mechanisms and media of energy distribution) of the chosen terminal units are summarized in Table 1.

Table 1. The chosen terminal units and corresponding possibilities, limitations and characteristics (Y: Yes, N: No, NC: Not Common).

		Possibilities				Method of heat emission or removal				Capacity (W/m^2)		Medium of energy distribution		
Name of terminal	Type	Heating	Cooling	Ventilation (fresh air)	Humidification + Dehumidification	Convection	Mainly convection	Radiation	Mainly radiation	Heating	Cooling	Air	Water	Electricity
Radiant systems	Floor*	Y	Y	N	N	Y	N	Y	N	99	42	Y	Y	Y
	Wall	Y	Y	N	N	Y	N	Y	N	160	72	N	Y	Y
	Ceiling	Y	Y	N	N	Y	N	Y	N	42	99	Y	Y	Y
Air systems**	Mixing ventilation	Y	Y	Y	Y	N	Y	N	N	34°C	14°C	Y	N	N
	Displacement ventilation	Y/N	Y	Y	Y	N	Y	N	N	NC	18°C	Y	N	N
	Personalized ventilation	Y/N	Y	Y	Y	N	Y	N	N	NC	20°C	Y	N	N
Beams	Passive	Y	Y	N	N	N	Y	N	N	NC	80	N	Y	N
	Active	Y	Y	Y	Y***	N	Y	N	N	50	120	Y	Y	N

*: Floor in the occupied zone.
**: For air systems, typical maximum and minimum supply air temperatures are provided [11]. The heating and cooling capacity will depend on the ventilation rate.
***: Humidification and dehumidification is possible with the primary air and it should be done by the air-handling unit. Beams operate in dry, non-condensing conditions.

Dynamic building simulation softwares, Computational Fluid Dynamics (CFD), and experimental methods could be used to evaluate the performance of different terminal units, in terms of energy performance, resulting temperature and humidity fields, and occupant thermal comfort.

In addition to the characteristics that were addressed in this paper, there are several factors to consider when selecting a terminal unit (excluding the capital and operational expenditures):

- The chosen type of heating and cooling strategy (terminal unit) will have a remarkable effect on the occupant thermal comfort, and criteria such as noise, draft, vertical air temperature difference, etc. could be limiting factors for the choice and application of different terminal units. The international standards (EN 15251:2007 [21], EN ISO 7730:2005 [30], ASHRAE 55-2010 [31]) should be followed to provide the optimal thermal comfort for the occupants.
- It is crucial to consider the transportation and auxiliary energy consumption (pumps, fans, valves, dampers, sensors, etc.) associated with each terminal unit.
- Availability (depending on the location, natural resources, district heating or cooling network, etc.) of the energy sources and sinks, and the possibility of coupling with the terminal unit should be considered.
- Control possibilities and principles (e.g. individual room or zone control, control based on flow rate, supply temperature, average temperature, as a function of air temperature, operative temperature or outside temperature) and dynamic behaviors of the terminal units should be considered, e.g. ventilation systems try to keep a constant room temperature while TABS allows a certain temperature drift and keeps the operative temperature within the comfort range rather than a constant value [4]. Another example of the dynamic behavior is the difference between a TABS and a radiant panel, where the radiant panel will be able to affect the thermal conditions in the room faster than a TABS construction, due to its significantly lower thermal mass.

When deciding on which terminal unit to use in a space, all of these issues (occupant thermal comfort, transportation and auxiliary energy consumption, possible use of heat sources and sinks, control and dynamic behavior) and the possibilities, limitations, and capacities provided in this paper should be considered.

Acknowledgments

The authors' participation in IEA EBC Annex 59 was funded by EUDP (Energiteknologisk udvikling og demonstration), project no. EUDP-12-I 2012. The authors thank the working group of Annex 59 (in particular, Dr. Jérôme Le Dréau) for the constructive discussions.

References

[1] International Energy Agency. (2015, February 22). Retrieved from International Energy Agency's Energy in Buildings and Communities Programme: http://www.iea-ebc.org/

[2] IEA EBC Annex 59. (2015, February 22). Retrieved from High Temperature Cooling & Low Temperature Heating in Buildings: http://www.annex59.com/

[3] Babiak, J., Olesen, B. W., & Petráš, D. (2009). Low temperature heating and high temperature cooling. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations.

[4] Olesen, B. W. (2012). Using Building Mass To Heat and Cool. ASHRAE Journal, 44-52.

[5] Olesen, B. W., Michel, E., Bonnefoi, F., & De Carli, M. (2000). Heat Exchange Coefficient Between Floor Surface and Space by Floor Cooling - Theory or a Question of Definition. ASHRAE Transactions, Part I, 684-694.

[6] Liu, X., Jiang, Y., & Zhang, T. (2013). Temperature and Humidity Independent Control (THIC) of Air-conditioning System. Springer-Verlag Berlin Heidelberg. doi:10.1007/978-3-642-42222-5

[7] Olesen, B. W. (1997). Possibilities and Limitations of Radiant Floor Cooling. ASHRAE Transactions, Part I, 42-48.

[8] Simmonds, P., Holst, S., Reuss, S., & Gaw, W. (2000). Using Radiant Cooled Floors to Condition Large Spaces and Maintain Comfort Conditions. ASHRAE Transactions, 695-701.

[9] ISO 18566. (2013). Building environment design - Design, test methods, control and operation of radiant heating and cooling panel systems. Geneva: International Organization for Standardization.

[10] ISO 11855. (2012). Building environment design - Design, dimensioning, installation and control of embedded radiant heating and cooling systems. Geneva: International Organization for Standardization.
[11] Cao, G., Awbi, H., Yao, R., Fan, Y., Sirén, K., Kosonen, R., & Zhang, J. (2014). A review of the performance of different ventilation and airflow distribution systems in buildings. Building and Environment(73), 171-186. doi:10.1016/j.buildenv.2013.12.009
[12] Müller, D. (Ed.), Kandzia, C., Kosonen, R., Melikov, A. K., & Nielsen, P. V. (2013). Mixing Ventilation - Guide on mixing air distribution design. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations.
[13] DS 469, 2nd edition. (2013). Heating- and cooling systems in buildings. Charlottenlund: Danish Standards. (in Danish).
[14] Recknagel, H., Sprenger, E., & Schramek, E.-R. (2011). Taschenbuch für Heizung und Klimatechnik. München: Oldenbourg Industrieverlag. (in German).
[15] Awbi, H. (2003). Ventilation of Buildings (2nd ed.). London: Spon Press.
[16] Skistad, H. (Ed.), Mundt, E., Nielsen, P. V., Hagström, K., & Railio, J. (2004). Displacement ventilation in non-industrial premises. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations.
[17] Melikov, A. K. (2004). Personalized ventilation. Indoor Air, 14 (Suppl. 7), 157-167.
[18] Melikov, A. K., Skwarczynski, M. A., Kaczmarczyk, J., & Zabecky, J. (2013). Use of personalized ventilation for improving health, comfort, and performance at high room temperature humidity. Indoor Air(23), 250-263.
[19] Fang, L., Clausen, G., & Fanger, P. O. (1998). Impact of temperature and humidity on the perception of indoor air quality. Indoor Air, 8(2), 80-90.
[20] Fang, L., Wyon, D. P., Clausen, G., & Fanger, P. O. (2004). Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance. Indoor Air, 14 (Suppl. 7), 74-81.
[21] EN 15251. (2007). Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels: European Committee for Standardization.
[22] Olesen, B. W. (2012). Revision of EN 15251: Indoor Environmental Criteria. REHVA Journal, 6-12.
[23] CR 1752. (1998). Ventilation for buildings - Design criteria for the indoor environment. Brussels: European Committee for Standardization.
[24] ASHRAE. (2013). ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[25] Woollett, J., & Rimmer, J. (Eds.). (2014). Active and Passive Beam Application Design Guide. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations.
[26] Virta, M. (Ed.), Butler, D., Gräslund, J., Hogeling, J., Kristiansen, E. L., Reinikainen, M., & Svensson, G. (2007). Chilled Beam Application Guidebook. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations.
[27] EN 14518. (2005). Ventilation for buildings - Chilled beams - Testing and rating of passive chilled beams. Brussels: European Committee for Standardization.
[28] EN 15116. (2008). Ventilation in buildings - Chilled beams - Testing and rating of active chilled beams. Brussels: European Committee for Standardization.
[29] ASHRAE. (2012). ASHRAE Handbook - HVAC Systems and Equipment. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[30] EN 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. Brussels: European Committee for Standardization.
[31] ASHRAE. (2010). ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.