SUMMARY OF DOCTORAL DISSERTATION (PHD)

Energy and exergy analysis of radiant cooling systems in buildings

by

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1 Introduction

According to the Directive 2010/31/EU of the European Parliament and the Council, buildings are responsible for 40% of energy consumption in the European Union. This share may rise in the following years due to the continuous increase of demand for comfort by occupants. In the buildings energy balance the share of cooling will increase either. Therefore any measure, which mitigates the buildings' energy consumption and helps the use of renewable energy sources, strengthens the security and independence of the European Union's and our country's energy supplies.

The climate change in summer (and transitional as well) seasons affects the efforts in reducing energy consumption negatively. The European climate will increasingly vary year by year due to global warming (Schär, et al., 2004). The existing systems will be less effective due to the negative effects of climate change. If we wish to be energy efficient, the building services need to be designed accordingly. It is therefore essential to use the most accurate data during the design process of cooling systems. Accordingly, the heat load must be calculated as precisely as possible in order to choose the most appropriate cooling system.

Office buildings are in use both in winter and in summer seasons and have significant heating and cooling demands. In these buildings, persistent, high quality intellectual work is performed; however it is not a sufficient condition for a person to "feel comfortable". The thermal comfort theory give the physical description of the suitable effective temperature. Four out of six parameters that are influencing the thermal comfort, can be influenced by the building service systems. For the comfort-focused building engineering design, it is required to have the most precise parameters of the examined building in regards of thermal comfort and heat-technological requirements, as well as the precise description of the external environmental parameters.

ISO 13790 and ISO 52016 standards provide internationally accepted algorithms to calculate the head-load (Lin, et al., 2016), (Li, et al., 2015). Using both algorithms the specific meteorological data of the location must be considered during the calculation. Furthermore, the conception of the building, the shape, the building materials used, the energy efficiency requirements set for a given region or country and the desired indoor temperature also need to be considered. (Kalmár, 2016), (Csáky, 2015), (Csáky & Kalmár, 2015), (Csáky & Kalmár, 2014), (Csáky & Kalmár, 2017) In my dissertation, the heat-load analysis was carried out by taking into consideration the registered solar radiation and temperature data of Debrecen, Hungary. During the research, I decided to focus on the transparent surface of the facades (e.g orientation, glazing and shading ratio).

Formerly, it was revealed, that the impact of the overall heat transfer coefficient of windows on the summer heat-load is negligible to its other physical properties. Furthermore, if the building is properly insulated, the heat flowing through opaque elements can be neglected, even if the aging process of the insulation must be considered. (MSZ EN ISO 52016-1, 2017). For calculating the heat-load, firstly the most important is to choose the proper calculation method. There are various possibilities (Pogran, et al., 2013), (Yang & Li, 2008), (Zhou, et al., 2008), (Yam, et al., 2003)). For my analysis, I investigated the two formerly used regulations in Hungary, which are still often used today, and are currently valid.

In comfort-circumstances, the heat loss of a person happens predominantly by radiation (42-44%), thus the technical solutions, which ensure the cooling through radiation, must be investigated; therefore I worked with surface cooling systems in my dissertation. The radiative cooling systems preferably demands continuous operation. These systems provide cooling using high temperature cooling water with low exergy-content. Thus, in case of high heat loads, it can happen that the radiative cooling system cannot neutralize the unnecessary heat quantity.. With surface cooling, the risk of local discomfort by draught in premises is less, than for other cooling solutions.

Since the European Union aims to increase the renewable energy ratio to 20% by 2020, compared to the 1990 levels, it is important to prefer those cooling solutions, where cold-energy is generated by using renewable energy sources. Therefore, to be environmentally conscious, the energy used by cooling systems ought to be gained from renewable sources.

Hence it is a major question, how these renewable energy sources can be integrated into these cooling systems. Using renewable energy sources, a heat can be produced directly, furthermore electrical energy indirectly and directly as well. The renewable sources potentially feasible for operating a cooling system are: solar-, geothermal-, water-, wind-energy and biomass. In the case of absorption chillers, primarily solar- and geothermal energy can be used efficiently.

Besides the quantitative (energy) analysis, from the perspective of optimal designing and operation of cooling systems, carrying out the calculations on the quality (exergy) is indispensable, so that the excessively complex question can be answered, as to which system is more effective, from heat-release, heat-transfer and heat-production point of view.

2 The objectives / hypotheses of the research

The main goal of my research work is to analyze radiant cooling systems from an energy and exergy point of view. The investigation goes from human and material protection needs to the source of energy production. Emphasized aspect of my analysis is that the results can be used in the short run in the designing of cooling systems. This is the reason why some steps focus on heat-load, cooling process, heat-transfer and cold heat-production in this scientific work.

The main objectives and hypotheses of my research:

1) The comparison between the nationwide known and used calculation methods of heat-load value
2) The analysis of the sensibility of one particular heat-load calculation on architectural attributes, which can be affected during a building restoration. My assumption is, that the heat-load value will be mostly affected by the extent of shading.
3) Since the substance protection is high priority regarding surface cooling, I set a goal to work out correlations, on which the highest removable heat-load value can be determined using surface cooling. My assumption is, that the greatest removable specific heat flux can be achieved using wall cooling.
4) Furthermore, my goal is to analyze the two most frequently used surface cooling methods (wall- and ceiling cooling) from the thermal comfort point of view. My hypothesis, is that there will be no significant difference between PMV – predictive mean vote and subjective thermal comfort answers (AMV – actual mean vote), and that they will converge to 0 (neutral state regarding thermal comfort).
5) Regarding practical use, I feel it is important to compare the mechanical compressor operated and the absorption chiller systems. I assume that, the less widely used absorption chillers will be better both in energy and exergy standpoints.
6) Heat flux values specific to a given device will appear in the index numbers of energy and exergy of absorption machines along with different operating temperatures. My goal is to partly, or fully separate the heat flux values from the index numbers.
7) I find it important to analyze efficiency of the solar energy and geothermal energy in the case of absorption chillers.

3 Usability of results

In my opinion, the results can be integrated independently into the designing part of the building engineering practice.

If we use some other method for the heat-load calculations, and not the one based on the revoked standard, the resulting data can differ significantly, which is the basis of the cooling system. The calculation method of the newer standards are based on up to date data and measurements that are more thorough. Therefore, if the practice does not follow this trend, the base parameters of the design will not be correct since the heat-load calculations are directly used for the selection of the cooling appliances.

I analysed the currently valid heat-load calculation methods, based on the sensibility of architectural attributes, which can be affected in newly built buildings, or in buildings in need of renovation. I found out that the most affected parameter for the heat-load calculation result is the glazing ratio on the facade. Then, the next step was the summary of radiation transmission capability („g”) and the shading ratio. It was observed that the ceiling cooling was be affected by all three of these. This meant that all the three parameters have major role in the ceiling cooling design process and before during the architectural design process.

Comfort measurements have revealed that the subjective AMV values are lower for the wall- and ceiling cooling systems, than the PMV values calculated with thermal data. Furthermore, it was revealed that the dissatisfaction towards the interior environment increases more slowly in case of ceiling cooling, than wall cooling after the cooling (and ventilation) are turned off. This raises the possibility of lowering the operating time of the ceiling cooling (as well), using either dry or wet technology.

I worked out new correlations for evaluating the energy transmission of the surface cooling system. These are capable of valuating the energy in a quantitative and quality point of view. It can be used to rate the design and build. The practical uses for the correlations, according to the established database, have showed that a room cannot be cooled by only cooling a single wall. Furthermore, it showed that it is unnecessary to produce cooling water under 10°C, since surface condensation would occur. I revealed that ceiling cooling should be avoided, if the building has more than 80% glazing ratio and western orientation. In addition, I have pointed out that with the temperature differentials utilized in practice, it is unnecessary to apply shading and high quality windows, in urban environment, as it is not sufficient for the ceiling cooling to cool the room itself. The glazing ratio has to be lowered and the window orientations need to be revised.

I compared the mechanical compressors in chillers and absorption chillers regarding energy and exergy demands. The results of the comparison were generalised and formed into mathematical correlations. This can be suitable for engineering designers to choose between the two types of chillers on the stated aspects. Obviously, some other aspects have to take into consideration as well (e.g. investment and operational costs).

I separated the energy and exergy index numbers of absorption chillers from the heat flux by introducing a new coefficient. Now the index numbers only depend by the temperature and the new coefficient. This gave the opportunity to compare different absorption chiller products.

I analysed the possibilities to utilize solar and geothermal energy source for absorption chillers. Considering the design of the machine, I came to conclusion, while both can be used, the utilization of solar energy source is more limited. For absorption chillers the parabolic trough type solar collectors are the most efficient, however it can only be used in low cooling capacity ranges.

Geothermal energy source utilization offers a wider range of opportunities. I showed that the machines could work with water retrieved from geothermal wells, though with quite low thermal efficiency. However, further deepening is possible at these wells. Both thermochemical and exergy efficiency increased drastically when the wells were drilled a few hundred meters deeper. The only restriction for this method was the existence of the water layer in the desired depth.