environmental sciences proceedings

MDPI

Proceeding Paper

Seasonal Performance Analysis of Three Air Cooling Systems for School Buildings †

María Jesús Romero-Lara [1,*], Francisco Comino [2] and Manuel Ruiz de Adana [1]

[1] Departamento de Química-Física y Termodinámica Aplicada, Escuela Politécnica Superior, Campus de Rabanales, Universidad de Córdoba, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain; manuel.ruiz@uco.es
[2] Departamento de Mecánica, Escuela Politécnica Superior, Campus de Rabanales, Universidad de Córdoba, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain; francisco.comino@uco.es
* Correspondence: p42rolam@uco.es; Tel.: +34-636-29-86-73
† Presented at the Innovations-Sustainability-Modernity-Openness Conference (ISMO'21), Bialystok, Poland, 14 May 2021.

Abstract: Efficient air cooling systems for hot climatic conditions, such as southern Europe, are required. Regenerative indirect evaporative cooler (RIEC) and desiccant regenerative indirect evaporative cooler (DRIEC) could be interesting alternatives to direct expansion conventional systems (DX). The main objective of this work was to evaluate the seasonal performance of three air cooling systems in terms of thermal comfort, ventilation and energy consumption. DRIEC was the recommended system to serve a standard classroom in terms of thermal comfort and RIEC in terms of ventilation and energy consumption.

Keywords: HVAC system; thermal comfort; ventilation; energy consumption; energy simulation

Citation: Romero-Lara, M.J.; Comino, F.; Ruiz de Adana, M. Seasonal Performance Analysis of Three Air Cooling Systems for School Buildings. *Environ. Sci. Proc.* **2021**, *9*, 14. https://doi.org/10.3390/environsciproc2021009014

Academic Editors: Dorota Anna Krawczyk, Iwona Skoczko, Antonio Rodero Serrano and Ewa Szatyłowicz

Published: 21 October 2021

1. Introduction

According to the Energy Efficiency of Buildings Directive, sustainable development and the achievement of competitive HVAC systems were established as main objectives [1]. Several research works analysed the energy behaviour of different hybrid HVAC systems [2]. Other authors carried out comparative studies between conventional and hybrid HVAC systems in terms of thermal comfort [3,4]. However, most of the works focused on the energy performance study [5].

The main objective of this work was to evaluate the seasonal performance of three air cooling systems in terms of thermal comfort, ventilation and energy consumption in school buildings.

2. Materials and Methods

2.1. Systems Description

Three air cooling systems were studied in the present work: (i) a conventional air cooling system based on a direct expansion unit (DX); (ii) an air cooling system based on a regenerative indirect evaporative cooler (RIEC); (iii) a hybrid air cooling system based on a desiccant regenerative indirect evaporative cooler (DRIEC). A schematic of the three air cooling systems is shown in Figure 1.

The DX system was mainly composed of an air-mixing box, a heating coil and a vapor-compression cycle, where the evaporator and the condenser were installed in a parallel arrangement.

The RIEC system works with a single inlet air stream (outdoor air, OA), which is divided into two air streams, exhaust air, EA, and supply air, SA. The outdoor air flow was cooled and supplied to the room without increasing its humidity ratio, and the exhaust air flow was humidified and heated and then exhausted outside.

The DRIEC system was mainly composed of a desiccant wheel and a heating coil to dehumidify the supply air and a RIEC to cool this stream.

The control systems of three air cooling systems were based on control by temperature, humidity and CO_2 concentration, in that order. The control strategies used had as their main objective to achieve thermal comfort conditions and reduce energy consumption.

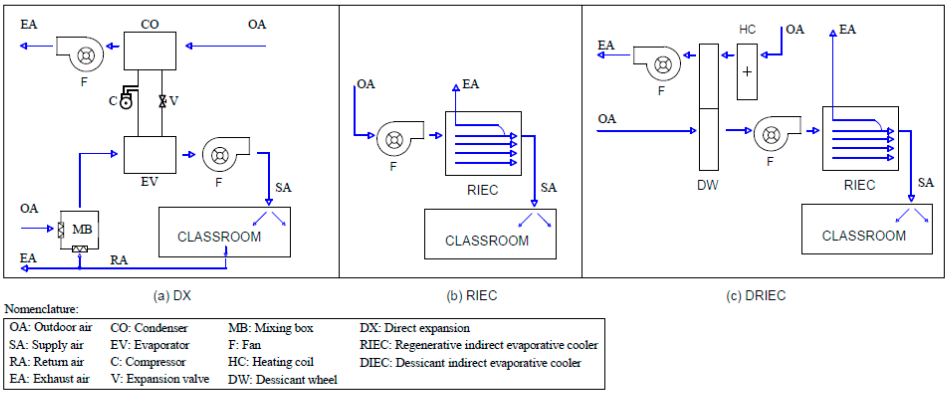

Figure 1. Schematics of (**a**) DX; (**b**) RIEC; and (**c**) DRIEC systems.

2.2. Building Model–Classroom

Detailed energy simulations were carried out with the assumption that the three HVAC systems served a standard classroom. The most important characteristics are shown in Table 1.

Table 1. Characteristics of the standard classroom.

Building	Floor area	55.8 m^2
	Height	3 m
Heat gain	People	20
	Sensible	60 W/person
	Latent	60 W/person
Daily Schedule	09:00 to 15:00 p.m.	

2.3. Energy Simulations

All of the air cooling systems elements were modeled from experimental data and integrated into TRNSYS17 software, using time steps of 2.4 min. The simulations were performed for the climate conditions of Lampedusa, an Italian island in the Mediterranean Sea, throughout the whole year.

2.4. Systems Evaluation

2.4.1. Thermal Comfort

Thermal comfort was evaluated according to predicted mean vote, PMV, and predicted percentage dissatisfied, PPD. Both parameters were calculated according to Standard UNE 16798-2 [6]. Four categories of thermal comfort were differentiated: (i) category I for PPD values less than 6%; (ii) category II for PPD values less than 10%; (iii) category III for PPD values less than 15%; (iv) category IV for PPD values less than 25%. The weighting factor, wf, calculated to determine the percentage of occupancy hours in each category was the ratio between the current PPD and the PPD limit.

2.4.2. Ventilation

A ventilation index was determined analogously to the thermal comfort evaluation method. Four categories of ventilation corresponding to ΔCO_2 difference between indoor and outdoor concentration (420 ppm) were considered: (i) category I for ΔCO_2 value less than 550 ppm; (ii) category II for ΔCO_2 value less than 800 ppm; (iii) category III for ΔCO_2

value less than 1350 ppm; (iv) category IV for $\Delta\Delta CO_2$ value more than 1350 ppm [6]. In this case, the wf values for each category were obtained with the real ΔCO_2 value and the limit ΔCO_2 value of each category.

2.4.3. Energy Consumption

The energy consumption of the air cooling systems was calculated as the sum of the energy consumption of each HVAC element, i.e., compressor, fans.

3. Results and Discussion

3.1. Annual Thermal Comfort Results

The annual results of thermal comfort for the three air cooling systems are shown in Figure 2. The bars show the percentage of time for each air cooling system working in each comfort category. In the present work, favourable comfort conditions were assumed when the indoor conditions were within categories I and II. It can be observed that the DX and DRIEC systems achieved similar favourable conditions (Figure 2). However, a significant reduction was obtained with the RIEC system, mainly due to the high humidity in the supply air.

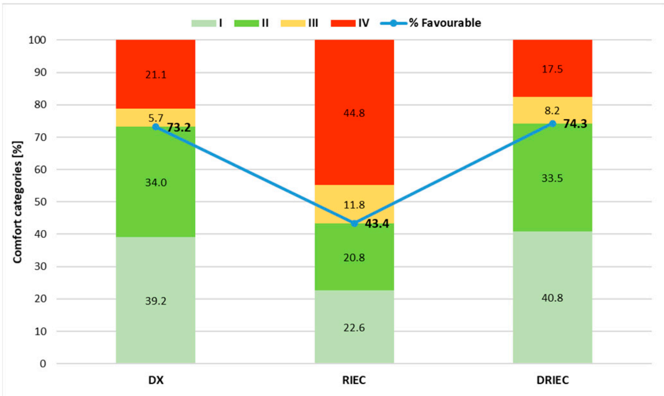

Figure 2. Thermal comfort results. Percentage of occupancy hours in each category.

3.2. Annual Ventilation Results

The annual ventilation results for the three air cooling systems are shown in Figure 3. The bars show the percentage of time for each air cooling system working in each ventilation category, and the categories I and II were considered favourable, as well as for thermal comfort. It can be observed that the DX system was in the unfavourable category throughout the occupation period, since only a low percentage of supply air came from outside. The RIEC and DRIEC systems achieved similar favourable conditions (Figure 3) because they are all outside air systems.

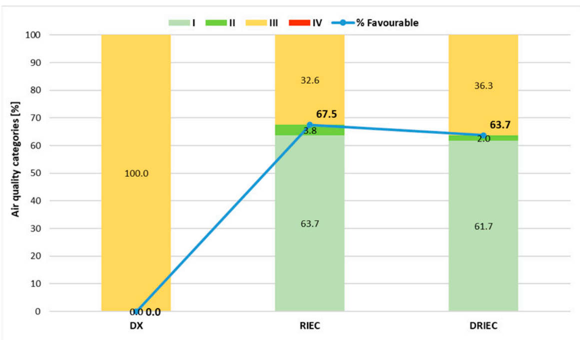

Figure 3. Ventilation results. Percentage of occupancy hours in each category.

3.3. Annual Energy Consumptiom Results

The annual energy consumption results for the three air cooling systems are shown in Figure 4. It can be observed that the RIEC and DRIEC systems had similar consumption during the occupation period. However, the DX system consumed three times more than the DRIEC system.

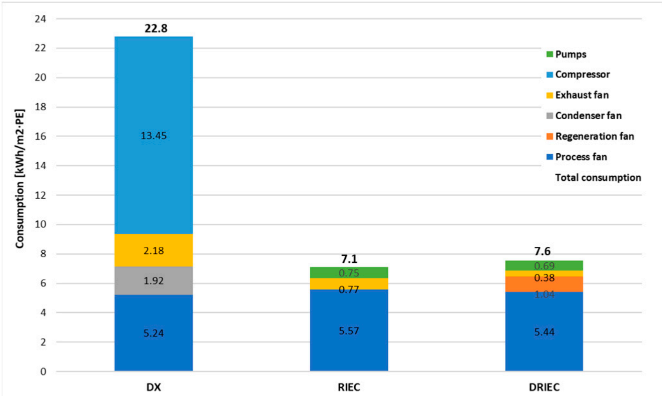

Figure 4. Annual energy consumption results.

4. Conclusions

In the present work, the performance of three air cooling systems were analysed. Based on the results obtained, the following conclusions can be drawn:

- Thermal comfort: The most favourable comfort conditions were obtained with the DX and DRIEC systems. However, the RIEC system achieved more unfavourable comfort conditions since the air supply humidity was not controlled.
- Ventilation: The air cooling system with the longest period in favourable ventilation conditions was the RIEC system, 67.5%. The DRIEC system reached 4% less than the RIEC. The DX system always worked in category III, the unfavourable category,
- Energy consumption: The systems with the lowest energy consumption were RIEC and DRIEC, up to three times less than the DX system.

Author Contributions: M.J.R.-L. analysed the data, discussed the results and wrote the paper; F.C. modelled all the air cooling systems and discussed the results; M.R.d.A. contributed to the development of the paper and discussed the results. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors acknowledge the financial support received by the European Regional Development Fund and the Andalusian Economy, Knowledge, Enterprise and University Council, Spain, through the research project HICOOL, reference 1263034, and the Postdoctoral Fellowship of the University of Cordoba, Spain, and by European Union's Horizon 2020 research and innovation programme, through the research project WEDISTRICT, reference H2020-WIDESPREAD2018-03-857801.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Congedo, P.M.; Baglivo, C.; D'Agostino, D.; Zacà, I. Cost-optimal design for nearly zero energy office buildings located in warm climates. *Energy* **2015**, *91*, 967–982. [CrossRef]
2. Comino, F.; Castillo González, J.; Navas-Martos, F.J.; Ruiz de Adana, M. Experimental energy performance assessment of a solar desiccant cooling system in Southern Europe climates. *Appl. Therm. Eng.* **2020**, *165*, 114579. [CrossRef]
3. Mumovic, D.; Davies, M.; Pearson, C.; Pilmoor, G.; Ridley, I.; Altamirano-Medina, H.; Oreszczyn, T. A comparative analysis of the indoor air quality and thermal comfort in schools with natural, hybrid and mechanical ventilation strategies. *Proc. Clima WellBeing Indoors* **2007**, *23*, c8.
4. Breesch, H.; Merema, B.; Versele, A. Ventilative cooling in a school building: Evaluation of the measured performances. *Fluids* **2018**, *3*, 68. [CrossRef]

5. Congedo, P.M.; D'Agostino, D.; Baglivo, C.; Tornese, G.; Zacà, I. Efficient solutions and cost-optimal analysis for existing school buildings. *Energies* **2016**, *9*, 851. [CrossRef]
6. CTN100-Climatización. EN 16798-1:2020. Energy Performance of Buildings—Ventilation for Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Module M1-6. 2020. Available online: https://standards.iteh.ai/catalog/standards/cen/b4f68755-2204-4796-854a-56643dfcfe89/en-16798-1-2019 (accessed on 1 May 2019).