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Benchmarking Thermal Comfort Performance of Two Residential Air Distribution Systems in a Low-Load Home

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1 Introduction

Despite broad recognition that air distribution plays an important role in thermal comfort for residential buildings, few studies have addressed the fundamental ability of residential air distribution systems to produce and deliver the selected setpoint temperature throughout a house over time. To address this deficiency, this paper compares the long-term thermal comfort performance of two air distribution systems using multiple benchmarks. The two systems, a Conventionally-Ducted Heat Pump (CDHP) and a Small Duct High Velocity (SDHV) heat pump, were used to condition the same test house, the Net-Zero Energy Residential Test Facility (NZERTF) that is located on the campus of the National Institute of Standards and Technology (NIST) in Gaithersburg, MD, USA.

2 Methods

This study analysed one-year of high resolution (i.e., 10-sec and 1-min interval) data that were collected at the NZERTF from September 2016 to August 2017. The NZERTF is a detached, single-family home that serves as a laboratory with simulated occupancy and scheduled internal loads (Pettit et al. 2015). The house provides a unique platform for comprehensive, accurate measurements to explore various designs, technologies, and control strategies to achieve net-zero energy performance. During the analysis period, the CDHP and the SDHV were operated alternately every other week in order to compare the two systems under similar weather conditions. Kim et al. (2019) provides more details on the tested systems and thermal comfort and system performance data collection.

The NZERTF results were benchmarked using metrics applied to other houses and air distribution systems, including the temperature deviation from the setpoint temperature, room-to-room temperature difference, cyclic discomfort, as well as the horizontal and vertical thermal stratification within a single room. The results were also compared against benchmarks in Air Conditioning Contractors of America (ACCA) Manual RS (1997) and ASHRAE Standard 55 (2017).

3 Results and Discussion

The results revealed the seasonal performance of the tested air distribution systems and the potential importance of data monitoring in the rooms that are not inhabited but are thermally important due to possible heat transfer from/to the primary rooms. For example, during the cooling season, the SDHV maintained better thermal uniformity than the CDHP (Figure 1). The average room-to-room temperature difference with the SDHV was 1.3 °C, which was lower than the ACCA average benchmark for cooling (1.7 °C). By comparison, the CDHP configuration resulted in an average temperature difference of 2.0 °C, and 0.8 % of the measurements exceeded the ACCA maximum benchmark for cooling (3.3 °C). When compared to 36 high-performance occupied houses in a hot and humid climate, as reported by Poerschke and Beach (2016), the SDHV also showed better thermal uniformity than that dataset based on the cumulative data above the 40th percentile in Figure 1, while the CDHP showed less uniformity.

However, for the heating season, the SDHV showed larger room-to-room temperature differences than the CDHP. The average room-to-room temperature difference of the SDHV was 1.3 °C, which exceeded the ACCA average benchmarks for heating (1.1 °C), while the CDHP had an average temperature difference of 1.1 °C. The observed seasonal differences between the two systems in whole-house thermal uniformity performance (i.e., room-to-room temperature difference) are partly attributable to the upper floor SDHV supply ductwork being entirely housed in the passively-conditioned attic, which resulted in cooler attic and second-floor temperatures during the cooling season but warmer attic and second-floor temperatures during the heating season.

The vertical and horizontal temperature stratification within a single room was analyzed using data collected from a 3 x 3 x 3 grid in a second floor bedroom. No significant amounts of horizontal and vertical stratification were observed for either system during the cooling season. However, during the heating season, the SDHV exhibited vertical stratification across the measurement grid, with the average air velocities being lower than the ACCA minimum (0.08 m/s), which indicates insufficient air circulation. However, the maximum vertical temperature difference of the SDHV (1.3 °C) was still significantly below the ASHRAE Standard 55 limit (4 °C for standing occupants).

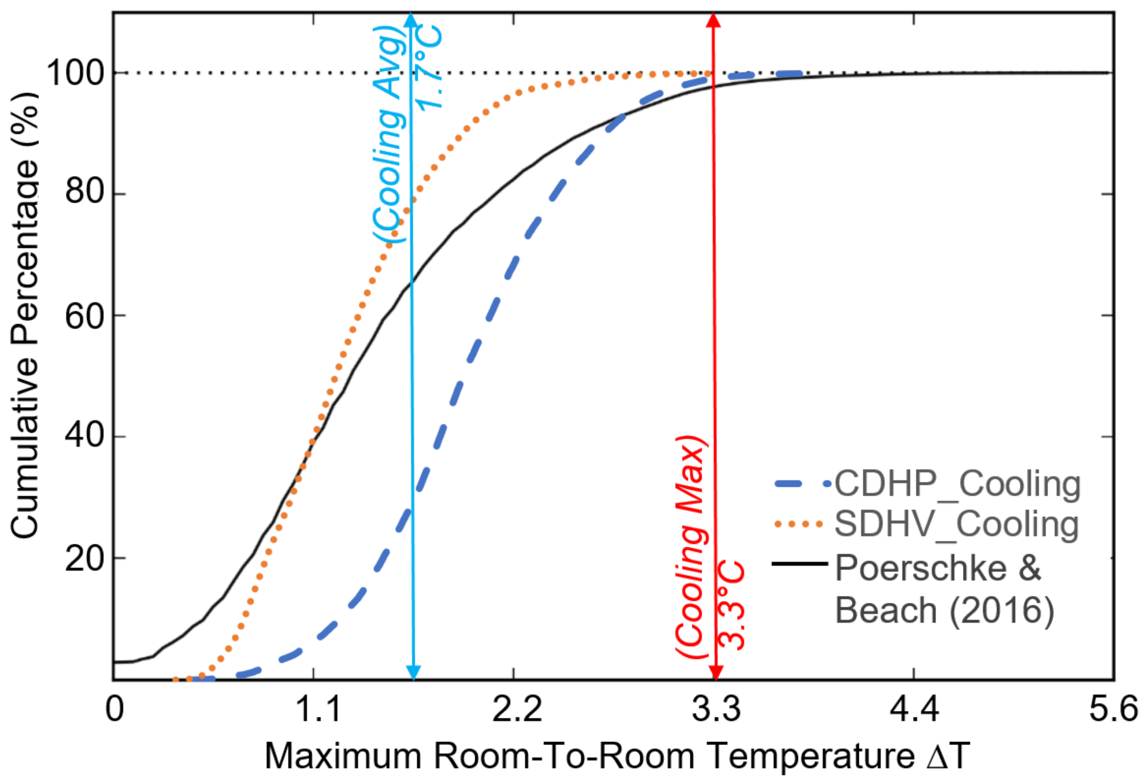

Figure 1: A Graphical Comparison of the Room-To-Room Temperature Differences.

4 Conclusions

This paper presents the results of benchmarking residential thermal comfort performance to study the HVAC system's ability to provide and maintain uniform space temperatures throughout the house. The ACCA Manual RS's primary focus on air temperature provides reasonable benchmarks for this study, since most residential HVAC systems are single-zone systems that are configured to control the thermal conditions of the house solely based on air temperature at the thermostat. There would be value in re-examining the ACCA Manual RS benchmarks, which were developed in 1997 based on HVAC systems and homes of 20 years ago, using more recent house and systems and more representative datasets for benchmarking.

5 Acknowledgement

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