ABSTRACT

Title of Document: Predictive Model Development and Validation for Raised Floor Plenum Data Centers

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Electronic data centers that handle enterprise and world wide web transactions typically consist of many servers, along with cooling units & power backup systems. With the explosion in digital traffic, the number of data centers as well as demands on each data center continue to increase. Concomitantly, the cost (and environmental impact of) energy expended in the thermal management of these data centers is of concern to operators in particular, and society in general. The most common data center is the air-cooled type, in which heat generated by computing and memory resources in servers is removed by computer room air conditioning (CRAC) units to maintain safe working temperatures inside the data center. In the absence of physics based control algorithms, CRAC units are typically operated at conservatively pre-determined set points, resulting in sub-optimal energy consumption. This problem is exacerbated in smaller, non-standard data centers that may be operated by relatively small enterprises who cannot own large, optimized data centers. For a more optimal control algorithm, predictive capabilities are needed. In this thesis, we develop a data-informed, experimentally validated and

computationally inexpensive system level predictive tool that can forecast data center behavior for a broad range of operating conditions.

Initially, we developed a steady state CFD model of a typical raised floor plenum (RFP) data center system and performed parametric analyses. An important conclusion from this study was that to accurately simulate fluid flow through plenum tiles (and into the data center), effective tile properties must be carefully selected to satisfy mass and momentum balance. Using this tool, we also quantified the impact of plenum chamber obstructions on steady-state data center performance. Once reasonable agreement with literature and experimental data was achieved, we developed a transient CFD model.

Experimentation on live data centers is a challenge, since an increased risk of service disruption is unacceptable. In such cases, a scaled down testing facility enables safe testing and validation of CFD models, and further, to evaluate candidate control strategies. We developed a bench-top test facility (20 times scaled down). Using this scaled-down facility, we established that the CFD models agree well with experiments. This bench scale prototype allows experimentation with various arrangements of server racks (such as conventional RFP or the so-called "s-pod" layouts).

We then performed dynamic thermal response experiments on a full-scale experimental raised floor plenum data center laboratory. At the server, rack and facility levels, the effect of server heat load, CRAC air supply temperature, and CRAC air flow rate were experimentally quantified. The transient CFD models for rack & system level were developed and validated against experiments. CFD solutions incorporating Navier-Stokes equations are computationally expensive for a real-time control of a data center. To reduce computational expense, we adopted a data driven model and expanded it for the system level non-linear multivariate problem.

The predictive modeling approach utilizes system input and output data to train a coefficient matrix. This coefficient matrix captures system information and is the key to mimic system dynamics in a predictive simulation. This coefficient matrix is unique to each data center; once the coefficient matrix is determined, the thermal behavior of the system can be predicted. We have tested this model against experiments as well as on (experimentally) validated transient CFD simulations. The validated model can accurately forecast temperatures and air flows in a data center (including the rack air temperatures) for ten to fifteen minutes into the future. Once integrated with control aspects, we expect that this model will form an important building block in a future intelligent, increasingly automated data center.

Dedication

To Dr. Pravin Shingane, my brother in law for his vision during my schooling that I could enroll into the prestigious institutes in India (IITs) and realize a higher potential. I was helping my parents at small Channa selling shop after school hours. It was Dr. Pravin who saw talent and potential in me by observing my hard work & sincerity in studies, and motivated me for further studies. Therefore, I am dedicating this thesis to him.