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Summary narrative of Research.pdf

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A summary review and brief narrative of published research results, organized according to topic

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Abstract
I recently had to provide a brief narrative of my published work, organized by topic. In case this is helpful to somebody researching one of these topics, I have included this narrative below, with some minor modifications from the original. I have tried to highlight the main or unexpected contribution from each work and to show connections and differences between papers on related topics to help guide a reader to the appropriate publication.

The work is organized into the following topics: building envelope; fan airflow modeling; multi-stack exhaust; ventilation; control of tankless water heaters (including model predictive control); evaluation of fault detection and diagnosis; and modeling vapor compression cycles with faults.

Thanks for your interest!

Building Envelope
In Yuill and Yuill (1998), we developed a method for determining the airtightness of individual construction elements of a house. The method uses results of blower door pressurization and depressurization tests conducted while various elements are sealed off, and provides a system for quantifying the impact of each element on the overall envelope performance. Several hundred blower door tests were conducted, and the method was found to be highly repeatable. Results from Yuill and Yuill (1997) show several interesting conclusions, among the most important being that the type of insulation used in a typical stick-built house has virtually no impact on the house airtightness. For example, a house with kraft-faced fiberglass batt, unfaced fiberglass batt, and blown-in cellulose batt installed and removed in series, had the same airtightness with each one. The reason is because leakage is dominated by large leaks, so the airflow rate through the wall cavities doesn’t play a significant role.

The drywall was found to be a significant element of the air barrier. Many elements were tested: the effect of drywall tape, paint, housewrap; foam sheathing; siding; expanding foam; etc.

Multi-stack Exhaust Systems
These papers propose using multiple small diameter stacks in place of a single large stack for rooftop exhaust in variable flow systems. In laboratories, for example, fume hoods with openable sashes vary
their flow rates. The velocity requirement for the stack exit means that the maximum flow rate is always required. The multi-stack system allows a combination of smaller stacks to meet the requirements at part-load. Wang et al. (2002a) describe the concept and its benefits; Wang et al. (2002b) and Liu et al. (2003) describe an optimization of the design for new installations and control of the system; and Wang et al. (2004) describe application in retrofits.

**Fan Airflow Modeling**

In Yuill et al. 2003 a fan airflow station was developed and tested. More recently these are referred to as virtual sensors. They are models that use easily measured variables to predict the values of more difficult measurements. This virtual sensor uses pressure differential across the fan and the variable frequency drive signal (a proxy for fan speed) to sense airflow rate through the fan. A third-order and a second-order model were tested, with no significant difference in performance. They were each found to be accurate with 2%, which is the uncertainty of the measurement instruments used to validate the model.

**Ventilation**

Yuill et al. (2008) describes an experimental study of the effect of secondary air paths, such as fan-powered air terminal units, on the ventilation effectiveness in a building served by a VAV system. This work provides a theoretical foundation for the variable $E_r$, used in ASHRAE Standard 62.1 for buildings with recirculating air distribution systems, and first defined by Warden (1995). It also describes tests that were conducted, using sulfur hexafluoride as a tracer gas, to determine the levels of $E_r$ that are possible in real buildings. It is found that theoretically, $E_r$ can range from 0 to infinite, but in an office building it more typically would be from 0.14 to 1.13. This means that well-placed entrances to secondary air paths can be used to reduce total building ventilation rates while maintaining acceptable ventilation. Yuill et al. (2010) tested how well ventilation air mixes within a building, again using tracer gas measurements. It was found that the notion that typical buildings are well mixed is not true. This experimentally validated the system ventilation efficiency equation (sometimes called the multiple spaces equation) of ASHRAE Standard 62.1.

**Control of Tankless Water Heaters**

Henze et al. (2009) describes the development of a controller for tankless water heaters that uses model predictive control (MPC). This control application is very difficult because of the non-linearity of the thermal process, which is subjected to rapid changes in water flow rate in typical application. The dynamic model is developed using a combination of forward and inverse modeling, and is tested experimentally. In Yuill et al. (2010) a method is proposed for quantifying control performance for tankless water heaters, and this method is applied to a water heater that is controlled using several different control methods, including MPC. A surprising and valuable result is that far simpler methods slightly outperform MPC. This result is valuable because MPC is very expensive to develop. The overall top-performing method is a combination of feed-forward and PID feedback control. Theoretically, MPC should be able to match this method, but the difficulty of tuning MPC means that it was performing suboptimally during the experimental testing. A more comprehensive report that includes a description of the test setup is given in Yuill (2008).
Evaluation of Fault Detection and Diagnosis (FDD) methods

Yuill and Braun (2012) propose a preliminary standard methodology for evaluating the performance of FDD tools that are applied to unitary air-conditioning equipment (e.g. split systems and rooftop units). No previous standard methods for evaluating FDD performance have been published, either for HVAC or other applications. In Yuill and Braun (2013) a significantly improved methodology and formal method is presented, which contains concepts from the 2012 method, but organizes results and performance metrics on the basis of the impact of the fault on performance. The method uses as inputs the laboratory measurements from eight systems. This paper also proposes standard terminology and definitions required for discussion of FDD performance. A summary of the method and some results from testing case studies of FDD methods are presented in a report (Braun et al. 2013) and in a book chapter (Yuill and Braun, 2015). The method is coded into a standalone software package called FDD Evaluator 0.1 (Braun and Yuill, 2013). In FDD Evaluator 1.2 (Yuill and Braun, 2014) simulation data are used for evaluation.

In Yuill et al. (2014a) it is argued that a large number of inputs is needed, so that evaluation must be done with simulation data, rather than laboratory data, as inputs. They prove this by comparing the results of evaluations done using simulation data from Cheung and Braun (2013a, 2013b) to evaluations done using all available laboratory-gathered fault data. In Yuill et al. (2014b) the models of Cheung and Braun are validated for use in FDD evaluation. The method, and simulation data, are coded into an online software application, FDD Evaluator 2.0 (Yuill and Braun 2015), which allows an FDD tool developer to test his or her algorithms interactively.

Yuill and Braun (2016a) systematically studies the effects of the distribution of faults (by both fault type and fault intensity) and operating conditions, showing that the performance of current methods is highly dependent upon these distributions. This points to the need for a standard set of condition, fault types, and fault levels for evaluation of FDD, in order to provide meaningful comparisons. The conditions should be tied to expected conditions in the deployment of the tools.

Yuill and Braun (2016b) propose a method for calculating the holistic value of an FDD tool. Yuill and Braun (2017) present a figure of merit (FOM) for determining the overall value of an FDD tool for a single application. The FOM considers a fault’s ramification on annual energy cost, equipment wear, and service, and uses an assumed probability of the occurrence of faults (by both fault type and fault intensity). It relies on a large library of input data from the models of Cheung and Braun (2013a, 2013b). A complete discussion is presented in Yuill (2014), but some details and results are not as up-to-date as in Yuill and Braun (2017).

In Yuill and Braun (2017) a case study shows that significant value is possible with effective FDD tools, but most of the tools tested in a case study of currently-deployed methods are found to give negative value (they impose more cost than benefit). The commercially available tool that provides the most benefit is one that strategically tolerates faults that will not be cost-effective to address (i.e. low impact faults, and faults with significant repair costs). This is a significant finding that should be factored into decisions in development and adoption of FDD tools.

Yuill (2016) discusses evaluation of FDD for air-conditioners with a specific focus on automotive air-conditioners.
Behfar et al. (2017) discuss the specific application of supermarkets, and a particular focus on refrigeration systems, which are known to have refrigerant leakage with significant environmental impacts (EPA, 2011). This paper summarizes the state of FDD for supermarkets, and presents an analysis evaluating various classes of methods (rule-based, model-based, and data driven) and some specific methods, using a large data set gathered from several supermarkets. It concludes that refrigeration FDD is still a nascent topic, and needs to consider controls when applied at the system or component level.

**Modeling Vapor Compression Refrigeration Cycles**

Mehrabi and Yuill (2016) present an analysis of all known laboratory results on the effects of refrigerant charge variation on split systems and packaged units, in both heating and cooling mode. In Mehrabi and Yuill (2017a) they propose a statistical method for generalizing these effects into simplified prediction models, and argue that the non-dimensional effects are sufficiently homogeneous that it’s reasonable to make predictions for systems that haven’t been measured. Yuill and Mehrabi (2017) discuss these models from the perspective of building energy simulation, and provide some specific models. Mehrabi and Yuill (2017b) is a companion paper to Mehrabi and Yuill (2017a), and provides similar results for faults other than charge variation, including evaporator and condenser fouling, liquid line restrictions, non-condensable gas, and compressor leakage.

Yang et al. (2013) proposes a simplified method for validating regression models based on performance rating data.

**References**


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