LBNL# 40102

Field Investigation of Duct System Performance in California Light Commercial Buildings

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Synopsis

This paper discusses field measurements of duct system performance in fifteen systems located in eight northern California buildings.

Abstract

Light commercial buildings, one- and two-story with package roof-top HVAC units, make up approximately 50% of the non-residential building stock in the U.S. Despite this fact little is known about the performance of these package roof-top units and their associated ductwork. These simple systems use similar duct materials and construction techniques as residential systems (which are known to be quite leaky). This paper discusses a study to characterize the buildings, quantify the duct leakage, and analyze the performance of the ductwork in these types of buildings.

The study tested fifteen systems in eight different buildings located in northern California. All of these buildings had the ducts located in the cavity between the drop ceiling and the roof deck. In 50% of these buildings, this cavity was functionally outside both the building's air and thermal barriers. The effective leakage area of the ducts in this study was approximately 2.6 times that in residential buildings.

This paper looks at the thermal analysis of the ducts, from the viewpoint of efficiency and thermal comfort. This includes the length of a cycle, and whether the fan is always on or if it cycles with the cooling equipment. 66% of the systems had frequent on cycles of less than 10 minutes, resulting in non-steady-state operation.

1. Introduction

Light commercial buildings, primarily one- and two-story buildings with individual HVAC package roof-top units serving floor areas less than 10,000 ft^2, make up a significant portion (50%) of non-residential building stock in the U.S. and California. Commercial retail strip-malls are among the largest percentage of light commercial buildings. This stock also consists of offices, restaurants and professional buildings.

First-cost dominates construction practices in these buildings. This potentially leads to short-cuts in construction practices and/or using lower grade materials. Often resulting in buildings which appear visually distressed five to ten years after they are built; moisture damage due to leaky roofs, and uncontrolled infiltration being the most common visual indicators of problems. The buildings use package roof-top units for HVAC, and as with the buildings, if not to a greater degree, first-cost dominates, with the same potential problems of poor construction practice and/or lower grade materials.

Slowly the industry, and research community, is acknowledging that duct-work in residential HVAC systems leak, sometimes by a very large amount. Roof-top units in commercial buildings use the same duct-work and installation techniques as residential systems (combinations of sheet-metal, duct-board, and flex-duct). Considering construction standards and practices, it would be a surprise if ducts in small commercial systems did not leak. The industry acknowledges that the ducts "may" leak, but since, in commercial buildings, the ducts are largely inside the building, there has been little interest in their performance, and in quantifying the extent of and the impact of duct leakage. While the ductwork may be physically inside the building, inside the ceiling cavity, this cavity is often outside the building's thermal and air barrier, thus ducts in many light-commercial buildings are subject to the same loss mechanisms as residential ducts located in attics.

1.1 Other Work

Researchers have recently documented the leakage characteristics of residential ducts. This study uses data obtained at LBNL for various studies (Jump, et al., 1996). Other than anecdotal evidence, the only significant work in the area of small commercial systems is from the Florida Solar Energy Center (FSEC). FSEC looked at the entire building envelope in a study titled "Uncontrolled Air Flow in Non-Residential Buildings" (Cummings, et. al., 1996). Their primary concern was with uncontrolled flow across the building envelope, and they did envelope leakage studies in 70 light-commercial buildings. Since ducts often dominate building leakage, they also performed duct leakage measurements in 43 of these buildings.

1.2 Goals

The goals for this current study fell in three basic areas: characterization of the building and HVAC systems, measurement of duct leakage area, and measurement system and register flows. Characterization involved identifying HVAC unit sizes, occupied areas, and the location of the thermal and air barriers. The goals of duct leakage information were measurement of fan and register flows, along with direct leakage area measurements.

The goals for this current study fell in three basic areas: building and HVAC system characterization, duct leakage, and duct thermal losses. Characterization involved identifying unit sizes, occupied areas, the location of the thermal and air barriers, and the system-fan and register flows. Duct leakage came from direct leakage area measurements. Single-day temperature monitoring yielded information on thermal losses.

2. Methods

Building selection consisted of buildings with package roof-top cooling systems, whose owners/occupants were willing to cooperate with the study. All of the buildings in this study were occupied, which meant working around the schedules of the occupants. This required the tests to be as non-obtrusive as possible, and consisted of three distinct parts: walk-through characterization, leakage and flow measurements, and thermal measurements.

2.1 Buildings

There were eight buildings involved in the current study, three of which were LBNL office spaces. The remainder were: a Stockton area office building, an office space located in a Sacramento area industrial park, a shoe repair store located in a Sacramento area strip-mall, a health food store in Marin county, and a Marin county gymnastics facility. In total, we tested a total of fifteen HVAC systems in these eight buildings.

2.2 Walk-Through Information

A simple walk-through with the occupants yielded most of the characterization information. Major items of importance were the name plate information on the HVAC equipment, duct material and location, building thermal barrier, and building air barrier. Other items such as occupancy schedules, internal loads, etc. were obtained by filling out a questionnaire with the building occupants. Appendix A contains the questionnaire and the protocol for this study.

2.3 Flow Measurements

Fan-flow measurements were measured with the tracer-gas method outlined by Delp, et al. (Delp, et al. 1996). Due to the restrictions of working in an occupied building, register-air flows were measured using a flow hood only.

2.4 Leakage Measurements

This study measured effective leakage areas using a modified duct pressurization method, as shown in Appendix B. The method uses a single set-up to measure the combined leakage area of both the supply and return duct systems. By using the HVAC unit as a flow meter, it is possible to determine the breakdown of return and supply leakage. Leakage area calculations are proportional to the flow into the system. Therefore, uncertainties in leakage area are proportional to the uncertainties in measuring the flow into the system. Since the uncertainties in measuring the flow are within 5%, the same range applies to the leakage are values.

2.5 Thermal Measurements

This study used small, battery-operated self-contained temperature loggers for all the thermal measurements. These loggers have a resolution and accuracy of approximately 0.2^{O}C, and store 1,800 data points. A collection interval of 12 seconds allows six hours of data storage. The loggers have a delayed start feature, allowing them to be left in place to start simultaneously at a pre-determined date. We collected the following temperatures: outside air, ceiling cavity, room, supply plenum, and at least one supply register.

3. Results

Results are presented in four primary sections: building and HVAC characteristics, duct leakage area, thermal issues, and occupant interactions.

3.1 Building and HVAC Characterization

Figure 1 shows the floor area versus the unit size, for both the LBNL and the FSEC data sets. Since the FSEC data set is larger, whenever the appropriate data is available, we use it for comparison. The important point here is the floor area served by each unit. This figure shows that the California (LBNL) buildings are similar to those in Florida (FSEC). Light-commercial buildings frequently have a greater load density (ton/ft^2) than single-family residential homes, due to internal loads such as equipment, lights, and people. Unfortunately with most light-commercial buildings accurate load information is not available during design, and contractors/engineers resort to a rule-of-thumb approach to equipment selection, often resulting in oversized equipment. It is worth noting the values in the figures are installed capacities, and do not necessarily correspond to actual space loads.

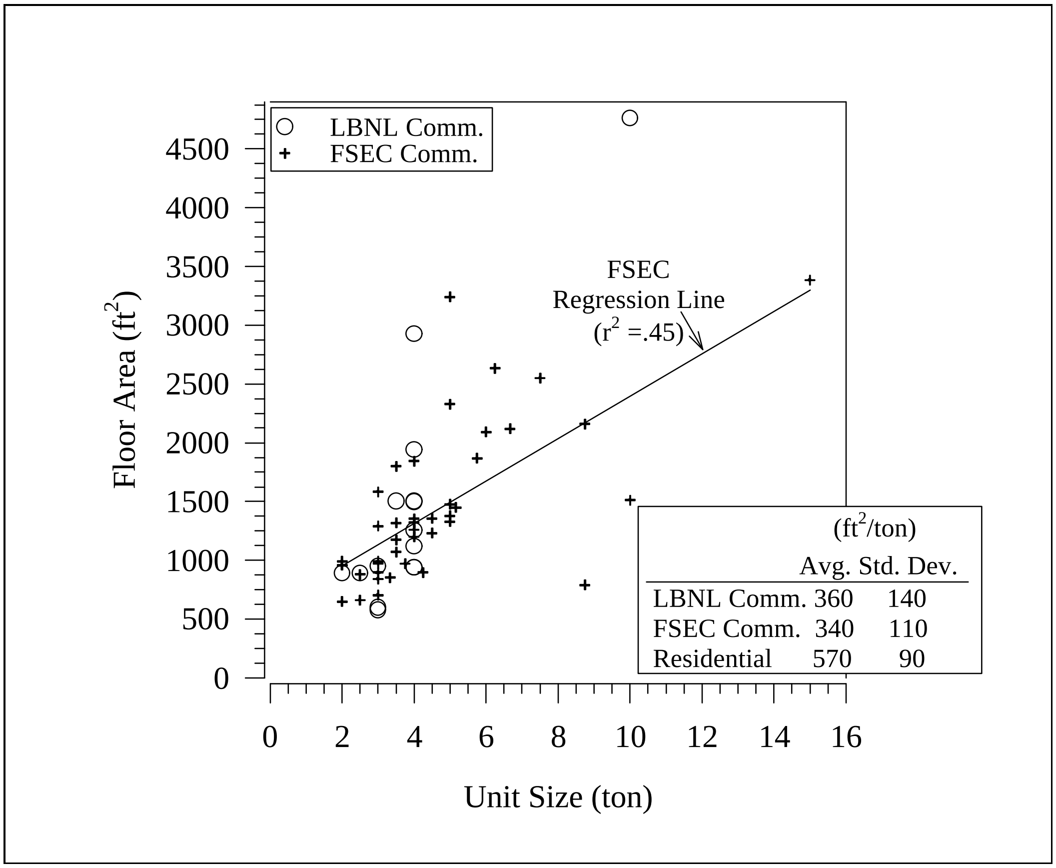

Figure 1. Floor area -vs- unit size: using the current LBNL and FSEC (Cummings, et al., 1996) commercial data along with residential (Jump, et al., 1996) summary information. The FSEC unit size is derived from the total installed capacity in the building divided by the number of units.

The fifteen systems had an average unit size of 3.9 tons, this compares with the FSEC data of 4.5 tons, and the residential of 2.9 tons.

The average floor area served by each unit was 1,500 ft^2 for the current study, 1,400 ft^2 for the FSEC buildings, and 1,800 ft^2 for the residential buildings. Since the area served by each unit is similar among all three data sets, the light commercial units are 30 to 50% larger than those found in single family residential houses.

Figure 2 shows the total number of registers (supply and return) versus the unit size. Since FSEC data on the number of registers was not available, the comparison is only with the residential data set. In both cases there is a widespread range in the number of registers for any given unit size, e.g., the number of registers found on a four-ton commercial unit ranged from 4 to 16. In general, the commercial units have fewer registers per ton than the residential units, because commercial spaces are usually open plan, with a few large rooms and fewer, but larger, registers.

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