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Unitary Air Conditioner Field Performance

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ABSTRACT

Service contractors around the country, during normal maintenance and service and as part of utility tune-up programs, measured the field performance of many unitary air conditioners using portable data acquisition systems. Data collected includes suction and liquid pressure and temperature, outdoor and indoor inlet air conditions, and unit descriptions. The potential for improving performance by resolving installation, maintenance and service issues was estimated from a compilation of this data. This paper describes the data and how it was collected and analyzed. Results include statistics on efficiency, superheat, and detected faults and their diagnoses.

1. INTRODUCTION

There is little data documenting the field performance of unitary cooling equipment. This data is valuable for estimating the potential benefits (e.g. energy savings, longer equipment life, and warranty cost savings) associated with helping resolve field issues and to suggest appropriate cost effective tools to help accomplishing this goal.

In 1992 and 1993, an HVAC/Refrigeration tune-up pilot program was implemented in Wisconsin to evaluate the effectiveness of HVAC and refrigeration tune-ups in saving energy and reducing peak demand in commercial buildings (Karmar, 1995). Nine sites were studied including retail and grocery stores, restaurants and an office building. The results varied widely, but energy savings of up to 15% were achieved in most buildings. Four major limitations to the study were sited

A two-year study by the Electric Research Power Institute that was concluded in 1997 investigated the energy and demand impacts of maintenance on rooftop packaged heating and cooling equipment (Krill, 1997). Six long-term and 24 short-term sites were monitored. The short-term sites established the immediate impact of savings and the long-term sites determined their persistence. The most consistent problem noticed was low refrigerant charge. No significant change in unit performance due to low charge, filter maintenance, or coil cleaning was observed. The study concluded that the cost of annual maintenance programs was unlikely to be offset by utility cost savings alone.

A Public Interest Energy Research (PIER) project (Jacobs, 2003) investigated inefficient design and installation practices in small HVAC systems, and recommended strategies for solving these problems. A total of 75 buildings and 215 rooftop units were studied with these results:

- 63% of economizers were malfunctioning.
- 46% had incorrect refrigerant charge.
- 39% had low airflow.
- There were numerous control related problems causing fans, heating and cooling to operate incorrectly.

Proctor 2004 recently released test results on over 55,000 units showing that:

- 95% of residential units failed the diagnostic test because of duct leakage, insulation or airflow restriction, refrigerant charge, evaporator airflow, unit sized too big or non-condensables in refrigerant.
- Charge in residential a/c units was incorrect 62% of the time.
- Charge in commercial a/c units was incorrect 60% of the time.
- Evaporator airflow in commercial a/c units is low 63% of the time.
- Recommended charging methods were not used 74% of the time.
- Correct airflow was not confirmed 72% of the time.

In April 2004, ASHRAE started a research project (ASHRAE, 2004) to study and document:

- The actual field performance of 375 packaged HVAC units and compare them to industry norms or manufacturer's specifications for new equipment.
- The implementation of diagnostic and proper service procedures and their resulting performance enhancement for at least 75 of the 375 units.
- The need for monitoring, FDD, and continuous commissioning technology to address the long-term service needs of packaged equipment in the field.
- The nature and frequency of any deficiencies and the corrective actions taken.

A research project with overlapping objectives entitled "Unitary Equipment Real Building Operating Conditions" is currently underway at ARI (Jones, 2001).

Data collected in this study includes suction and liquid pressure and temperature, outdoor and indoor inlet air conditions, and unit descriptions. This data was analyzed by first calculating performance indices including evaporating temperature, suction line superheat, condensing temperature over ambient and liquid line subcooling. Second, a model for normal performance determined expected values of these performance indices for the appropriate equipment type running under the measured outdoor and indoor conditions. Third, examining the difference between expected and measured values of these performance indices (i.e. residuals) identified equipment faults when appropriate. Fourth, models were used to estimate the energy savings potential associated with resolving detected faults. Compressor performance warnings were based on high and low suction line superheat.

2. DATA ACQUISITION EQUIPMENT

The data in this study was collected using a commercially available portable data acquisition system designed for vapor compression cycle performance assessments. The device has high and low side pressure sensors in a standard manifold gauge set, an integrated digital thermometer and a Personal Digital Assistant (PDA) that collects, analyzes and stores the data when the user is satisfied the test conditions are correct.

The pressure sensors have +/-1% full-scale (FS) accuracy with 780 and 380 psi full scale for the high and low sides, respectively. The sensors are additionally calibrated by zeroing at atmospheric pressure. Elevation-from-sea-level corrections are also made. The temperature sensors are Negative Temperature Coefficient (NTC) thermistors accurate to within 1°F and packaged appropriately for air and pipe surfaces temperatures as appropriate for different applications.

The pressure measurements include suction pressure (SP) on the low side and the liquid pressure (LP, preferred) or discharge pressure (DP) on the high side. If DP is used, a 15 psi pressure drop across the condenser coil was assumed to estimate LP. The temperature sensors included outdoor ambient (AMB), suction line temperature (ST) and liquid temperature (LT). The return air wet bulb temperature was either measured by the technician and hand–entered into the PDA or assumed to be the default value of 67°F, per the technician's judgment.

3. FIELD PROCEDURES

The data in this study was collected by service technicians in the normal coarse of doing business or as part of utility programs. The data was either collected while commissioning new installations, conducting equipment performance audits or repairing units. The sensors are installed according to normal field procedures and checked for correct installation by the software and the service technician. The unit is run for at least 10-15 minutes to achieve steady state. When the service technician is satisfied with the test results, he manually saves the data in the PDA. The data is transferred out of the PDA to our database via the Internet.

4. DATA ANALYSIS

The data summarized in this paper is a broad query of our database. It was collected on a broad range of unitary, air-cooled, direct-expansion and cooling-only/heat-pump equipment across the United States by a diverse selection of service technicians working for different organizations. Both residential and commercial equipment using both fixed orifice (FO) and thermostatic expansion value (TxV) metering devices are included. In the query, the first test record was returned for each site, unit and stage of cooling where the outdoor ambient temperature was >65°F, the two pressure and three temperature sensor readings were valid, the measurements produced a valid efficiency index (EI), and the technician entered the equipment setup data required for the energy cost savings estimate.

Equipment performance is characterized by the following performance indices, which were calculated from the instruments measurements:

1. Evaporating temperature (ET),
2. Condensing temperature over ambient (COA = CT – AMB, where CT is condensing temperature),
3. Suction line superheat (SH) and
4. Liquid line subcooling (SC).

Expected values of these performance indices (assuming no faults) are provided as a function of the type of equipment (e.g. expansion device, refrigerant, efficiency rating) and the measured driving conditions (AMB and RWB). A variable tolerance in the range of +/- 7°F to 10°F was placed around the expected values to provide high and low thresholds. If ET, COA and SH were all within tolerance, the unit’s performance was judged not have a fault. When there was a fault, a collection of diagnostic algorithms was used to suggest appropriate corrective action (e.g. fix high or low side heat transfer problems or add/recover refrigerant charge) to bring these performance indices back into tolerance. Compressor performance warnings are either high or low superheat, both of which may impact compresor durability depending on the compressor design and problem severity.

The efficiency index is calculated as the percentage of equipment efficiency when comparing current performance to the efficiency calculated based on the expected values of the four performance indices under the current driving conditions (AMB and RWB). Efficiency is estimated using a compressor model providing expected values of power consumption and refrigerant mass flow rate as a function of high and low side pressures and suction line temperature. Total unit power consumption was assumed to be the compressor power plus 20% for fans other small loads. Liquid and suction line enthalpies (in the refrigerant side capacity calculation) were provided assuming single-phase low.

EI was used to calculate potential energy cost savings ($/year) by considering the following four static properties of the equipment:

1. Cost of energy ($/kWh)
2. Nominal capacity (tons)
3. Nominal runtime hours (hours/year)
4. Unit efficiency rating

It was generally recognized that cost estimates were limited by the accuracy of runtime hour estimates since monitoring data (e.g. run hour meters) were not available. Run hours were obtained by published industry standards, estimating tools or other means available to individual service organizations.

5. RESULTS

The following figures illustrate the results of the data analysis as described above. 1468 independent vapor compression cycles are represented in these results.

Figure 1 – Frequency of Unit Faults

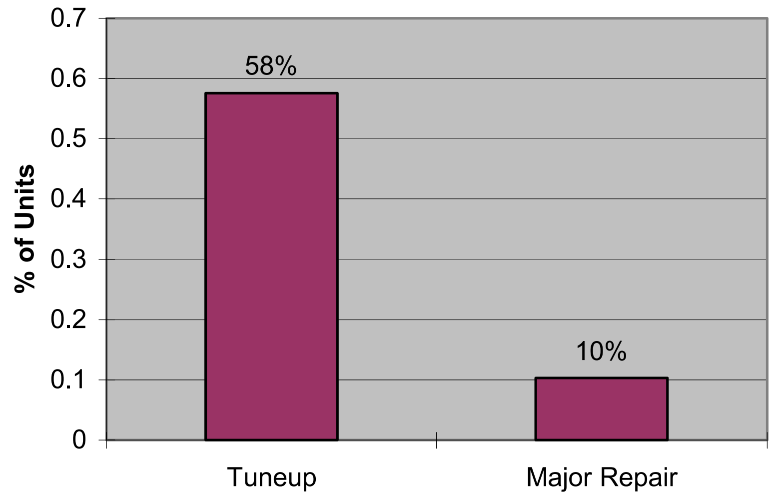

Figure 1 illustrates the percentage of units requiring either tune-up of major repair service. Combined, 2/3 of all units were judged to have a fault. 58% were tune-up related (e.g. fix high or low side heat transfer problems and add/recover refrigerant charge) and 10% require major repairs (e.g. refrigerant flow restrictions or compressor replacement).

Figure 2 - Frequency of Tune-up Faults

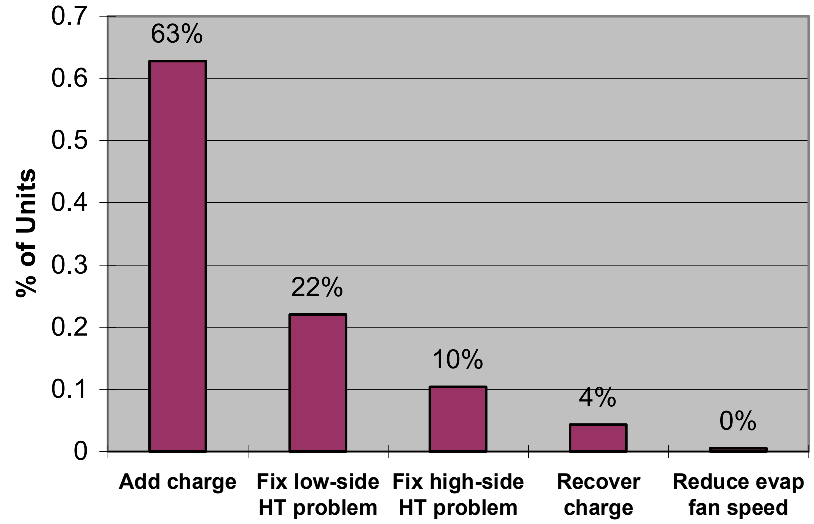

Figure 2 illustrates the frequency of various tune-up related tasks. Of the units requiring tune ups, 63% need charge, 22% have a low-side heat transfer problem (e.g. dirty evaporator coil), 10% have a high-side heat transfer problem (e.g. dirty condenser), 4% are overcharged and 1% have an evaporator fan running too fast.

Figure 3 - Compressor Performance Warnings

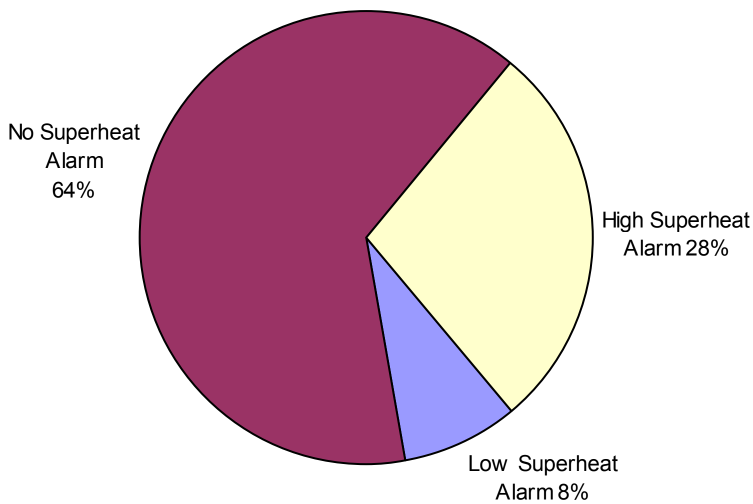

Figure 3 illustrates the frequency of compressor performance warnings as determined by either high or low suction line superheat. Low superheat raises concerns of liquid returning to compressors. Depending on the compressor's design and the severity of the problem, this may wash oil away from moving parts. High superheat raises concerns of reduced suction gas motor cooling. Again depending on the compressor's design and the severity of the problem, this may lead to motor winding degradation. One-third of all vapor compression cycles tested have compressor performance warnings. One-quarter of the superheat alarms are for low superheat and three-quarters are for high superheat.

Figure 4 – Superheat Residual Distribution

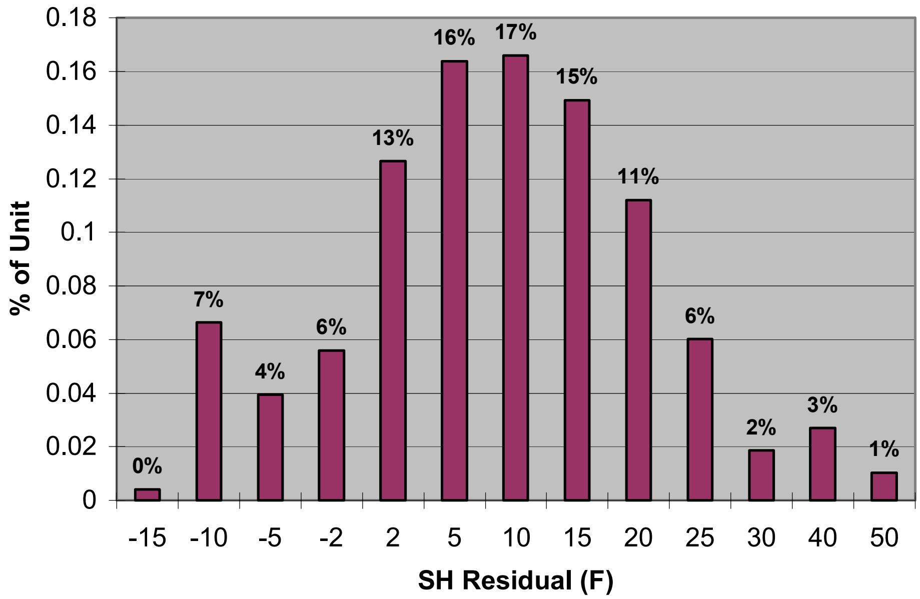

Figure 4 illustrates the distribution of superheat residuals (i.e. difference between actual and expected values). More equipment has higher-than-expected superheat rather than lower-than-expected superheat.

Figure 5 – Integrated Efficiency Distribution

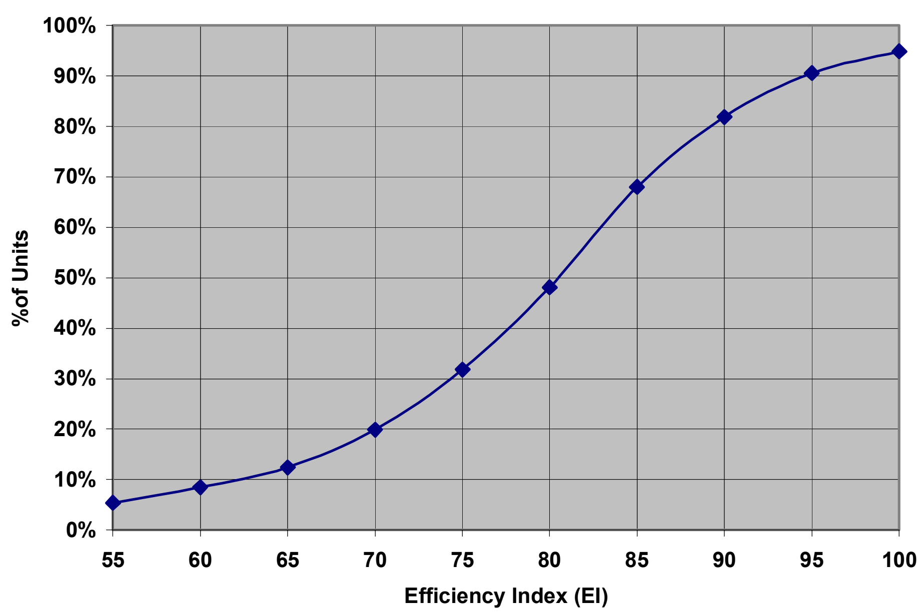

Figure 5 illustrates the distribution of integrated efficiency indices (EI). Approximately, 50% of units are running with 80% or less efficiency. 20% of units are running with 70% of less efficiency.

Figure 6 - Efficiency Distribution

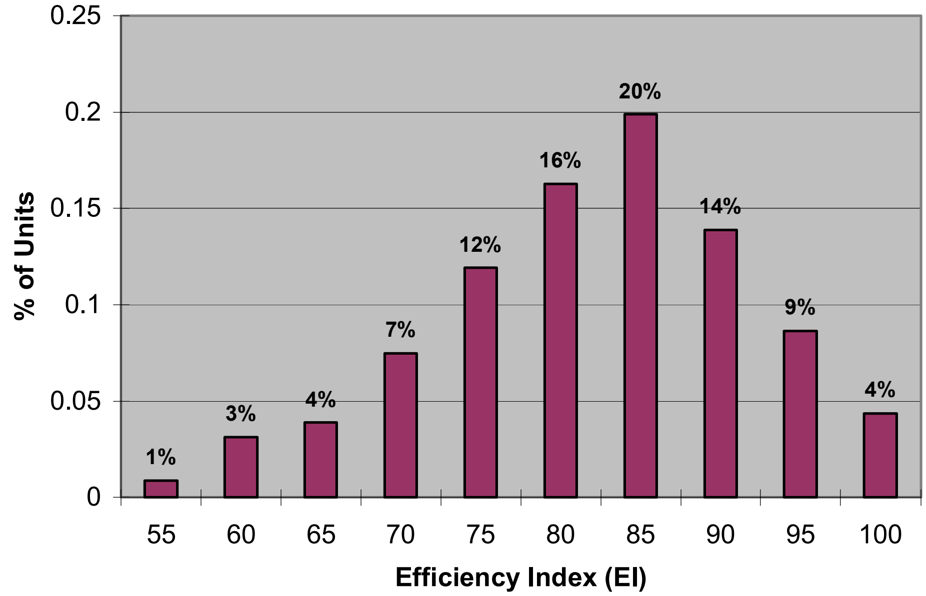

Figure 6 illustrates the distribution of cycle efficiencies. The average unit has efficiency is a little over 80%.

Figure 7 – Integrated Potential Energy Savings Distribution

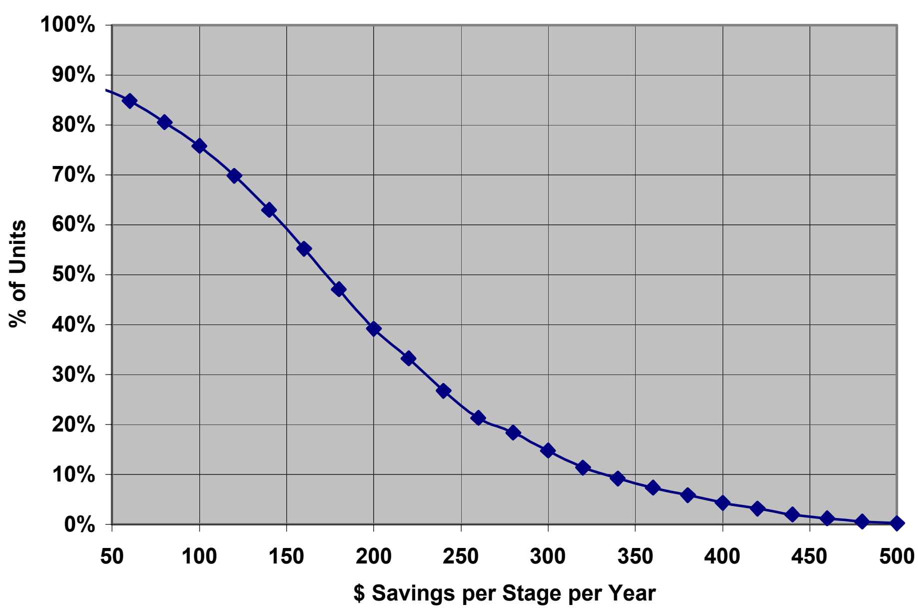

Figure 7 illustrates the integrated potential energy savings ($/year) resulting from the estimated efficiency degradation. 1/2 of the equipment has at least $170/year and 1/3 has at least $225/year of potential energy savings.

6. RESOLVING FIELD ISSUES

This paper helps estimate the potential benefits associated with resolving service field issues. Tools to help extract these savings on a large scale can either be embedded in new equipment or provided in a portable platform. Either way, cost effectiveness, especially on smaller standard-grade equipment (e.g. residential split systems), will be critical. Embedded solutions have the fundamental advantage of "continuous awareness". Among other technical and business issues, this helps resolve the uncertainty of estimating runtime hours for specific applications. Portable solutions have the key advantage of being less expensive since they may include little, if any, dedicated sensor or computing hardware on each unit. Other benefits of portable solutions include easier applicability to the installed base of equipment and the production of a "universal" solution that a service provider can apply to any piece of equipment. With creativity, the business objectives of all the various entities involved in this process can be addressed with either type of solution.

6. CONCLUSIONS

This paper helps estimate the potential benefits of resolving field service issues in unitary air conditioning equipment based on a broad spectrum of field service data. Of the 1,468 stages of cooling considered in this study, approximately 2/3 was judged to need service. 85% of those need tune-up related service (e.g. coil cleanings and charge adjustments) as opposed to major repairs (e.g. refrigerant flow restrictions and compressor replacements). One-third of the units tested have either high or low suction line superheat and, depending on the compressor design and the severity of the problem, this can potentially have an impact on long-term equipment durability. Approximately 50% of stages have efficiency of 80% or less and 20% of stages have efficiency of 70% or less as estimated by the described efficiency index (EI). These efficiency degradations were translated into potential annual cost savings by considering the nominal capacity, cost of energy, annual runtime hours and rated efficiency of each unit. 1/2 of the equipment has at least $170/year and 1/3 has at least $225/year of potential energy savings.

These field services issues can be addressed on a large scale with portable or embedded technology solutions, each with their advantages. Any solution will be critically cost sensitive, but with creativity a wide range of business objectives can be addressed using either platform.

NOMENCLATURE

Symbol	Description	Units
AMB	outdoor ambient temperature	(F)
DP	discharge refrigerant pressure	(psig)
COA	condensing temperature over ambient	(F)
CT	condensing temperature	(F)
ET	evaporating temperature	(F)
LP	liquid refrigerant pressure	(psig)
LT	liquid line temperature	(F)
SC	liquid line subcooling	(F)
SH	suction line superheat	(F)
SP	suction refrigerant pressure	(psig)
ST	suction line superheat	(F)

REFERENCES

ASHRAE, 2004, 1274-RP "Field Performance Assessment of Package Equipment to Quantify the Benefits of Proper Service", http://www.ashrae.org/content/ASHRAE/ASHRAE/ArticleAltFormat/2004323152130_347.pdf

Jacobs, P., Smith, V., Higgins, C., Brost, M., 2003, "Small Commercial Rooftops: Field Problems, Solutions and the Role of Manufacturers", National Conference on Building Commissioning.

Jones, E., 2001, "ARTI 21-CR Work Statement – Project SI-30080: Unitary RealBldg, Unitary Equipment Real Building Operating Conditions", ARI.

Karmar J., Valerie N., 1995, "Energy Impacts from Commercial Air Conditioning Maintenance – A WDSD Evaluation Report", Wisconsin Demand-side Demonstrations, 2901 W. Beltline Drive Suite 307, Madison WI 53713, (608) 275-7180, (608) 275-7199 (FAX).

Krill W. (EPRI Project Manager, Customer Systems Group), 1997, "The Impact of Maintenance on Package Unitary Equipment", TR-107273 3831, Electric Power Research Institute, 3412 Hillview Ave, Palo Alto CA 94304.

Proctor, J., 2004, "Residential and Small Commercial Air Conditioning – Rated Efficiency Isn't Automatic", ASHRAE Public Session, Anaheim CA, Meeting.

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