Building Energy Analysis Programs

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ABSTRACT

Building Energy Analysis Computer Programs consist of Loads, Systems, Plant, and Economic sub-programs. They are used by engineers and architects in the design and analysis of energy efficient building envelopes, heating, ventilating, and air conditioning, electrical and other service systems. The historical development of energy analysis programs is presented, the methodologies used in various programs are compared, and areas for future improvements are discussed.

INTRODUCTION

The use of computers in the design and analysis of building mechanical/electrical service systems was first accepted by the industry in 1965 when a group of mechanical engineering consultants organized Automated Procedures for Engineering Consultants, Inc. (APEC) to share software development costs. Their first program was the APEC Heating and Cooling Peak Load Calculation (HCC) Program (1) for use in designing the heating, ventilating and air-conditioning (HVAC) systems in buildings. This program was completed in 1967 and was designed to calculate peak heating and cooling loads and air quantities based on the input climatic data for the summer and winter design days. It relieved the design engineer of tedious hand calculations and provided data for the selection of heating and cooling plant equipment and the design of air distribution systems.

Most of the APEC members were also active members of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE); and in 1967, the ASHRAE Task Group on Energy Requirements (TGER) was formed. Procedures for determining heating and cooling loads for computerizing energy calculations were published in 1969 (2,3), consisting of the algorithms for building heat transfer sub-routines and the procedures for simulating the performance of components and HVAC systems. With such procedures the first generation of loads/energy programs were developed by the National Bureau of Standards (4) and the U.S. Post Office (5), which were placed in the public domain. During the same period, computer energy calculation programs were being developed in the private sector with proprietary data that did not always follow the ASHRAE procedures.

BUILDING ENERGY ANALYSIS PROGRAMS

Analysis of building energy demands and consumption generally involves three major steps, namely, thermal loads calculations, system simulation, and central plant simulation. Most building energy analysis programs are organized in such a way that each of these steps is analyzed by a separate sub-program. Some energy programs carry the program even one step further, into the economic analysis, and thus, consist of four principal computational programs: LOADS, SYSTEMS, PLANT, and ECONOMIC analysis. The differences in methods used in performing the calculations are essentially in the degree to which the mathematical models chosen for the simulation match "real world" conditions. Figure 1 represents a simplified flow diagram for an energy analysis computer program.

The LOADS program uses the building description information with weather data to calculate the heating and cooling loads of the building on an hour-by-hour basis throughout an entire year. These heating and cooling loads, both sensible and latent components, are responsive to the outside temperature, humidity, wind velocity, and solar conditions; schedules of people; lights and equipment; infiltration; time delay of heat transfer resulting from massive walls, roofs and floors; and to the effect of building shading on solar radiation. The LOADS program prints out a set of reports including peak heating and cooling loads by zone and building, and also generates an hourly file which will be used by the SYSTEMS program.

The SYSTEMS program uses the hourly load file output by the LOADS program as well as the user

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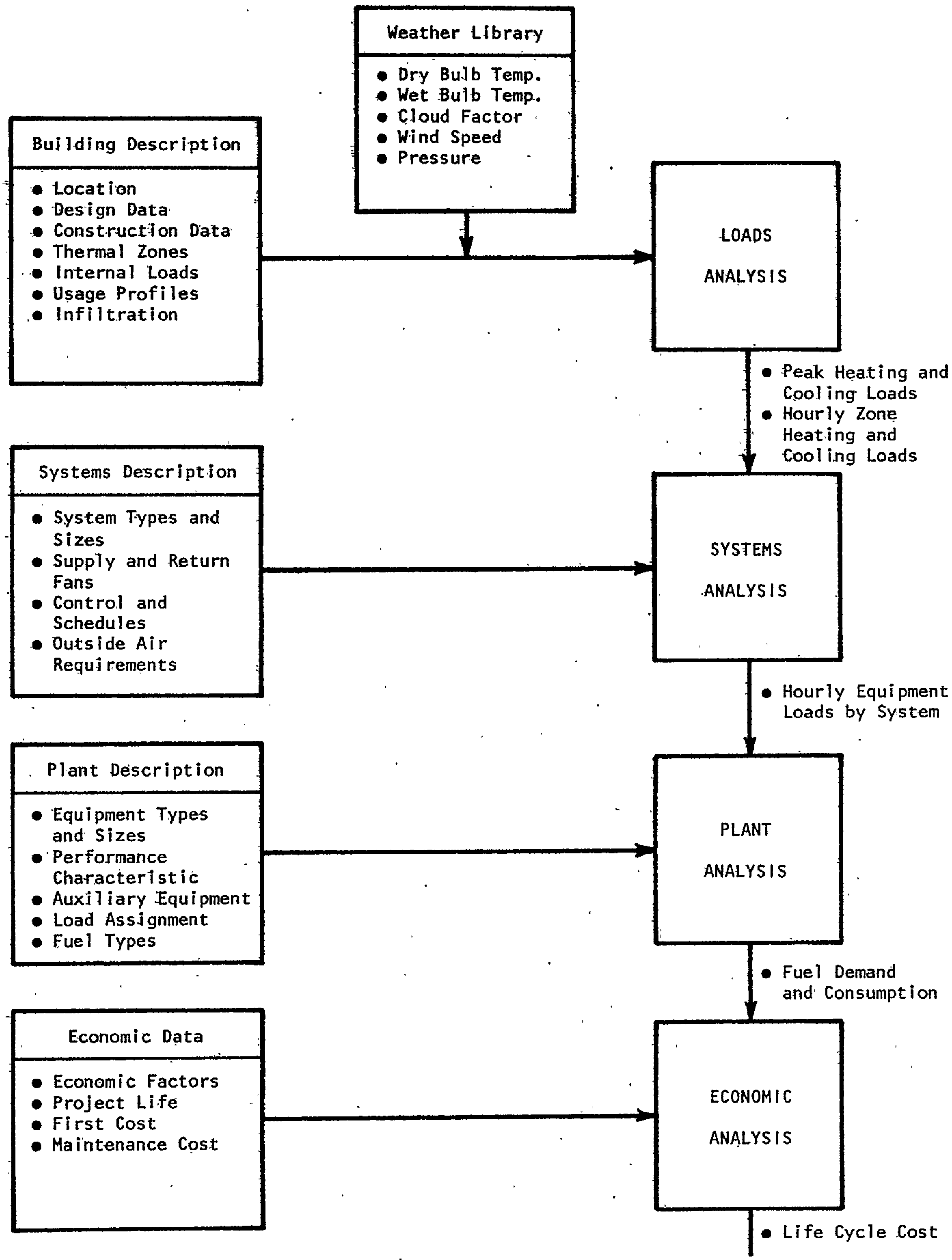

FIGURE 1: SIMPLIFIED BUILDING ENERGY ANALYSIS COMPUTER PROGRAM FLOW DIAGRAM

input system description to determine the heat extraction and addition rates actually required by the secondary HVAC systems. In the simulation, the program will take into account the outside air requirement, the HVAC equipment control schedules, supply and return fan power, and the operating characteristic of the system in maintaining the space temperature and humidity set points. It is these hourly rates of heat extraction and addition that are passed on to the primary HVAC system or the central plant.

The PLANT sub-program takes the output of the SYSTEMS sub-program and the user input of specific equipment to calculate the fuel and electrical requirements of the building and its energy systems. The simulation takes into account the part-load characteristics of the primary equipment, user specified priorities for distribution of the tasks among the several components, and their operation schedules.

The ECONOMIC sub-program combines the energy consumption by the building and its energy systems with pertinent economic input to perform the life cycle analysis. The input data generally includes building and equipment cost, maintenance costs, utility rates, interest rate, and inflation rates. The final output gives the capital investment and the present value of the operation costs for each year over the project lifetime.

USES OF BUILDING ENERGY ANALYSIS PROGRAMS

Building energy analysis programs can be of assistance to architects in building envelope design; mechanical engineers in heating and cooling systems design; electrical engineers in lighting design; operating engineers in determining of operating strategy; and government regulatory agencies in enforcement of building energy standards. The following alternatives may be considered to derive an energy conserving building and system design as well as operating strategy.

Building Design:

1. Building orientation.
2. Building geometry.
3. Exterior wall construction and insulation.
4. Roof construction and insulation.
5. Window areas and glass types.
6. Solar shading devices.

Lighting Design:

1. Lighting levels and types, e.g., incandescent vs. fluorescent.
2. Switching arrangements and controls.
3. Type of fixtures, e.g., ceiling suspended, recessed vented and/or unvented.

HVAC System Design:

1. Type of system, e.g., variable air volume vs. double duct or induction.
2. Type of fan control, e.g., variable speed vs. inlet vane control.
3. Economizer cycle, e.g., dry bulb vs. enthalpy controls.
4. Temperature controls, e.g., fixed vs. dead band zone thermostats.
5. Type of cooling plant, e.g., centrifugal vs. double bundle chillers.
6. Number of chillers, e.g., two large sizes vs. three smaller sizes.
7. Type of heating plant, e.g., gas boiler vs. electric duct heaters.
8. Heat recovery systems.
9. Hot and chilled water storage systems.
10. Solar systems.
11. Energy sources, e.g., natural gas vs. oil.

Operating Strategies:

1. Night temperature setback in winter and setup in summer vs. complete shutdown at nighttime and holidays.
2. Hot and cold deck reset temperatures.
3. Load assignment and load management of central plant equipment.

THE STATE OF THE ART

There are numerous computer energy programs available to the practicing engineer, but most of them are proprietary and were developed in the early 1970's using the Total Equivalent Temperature Differential Method (6). This simplified method was developed for calculating heat gains through exterior walls and roofs, and is only valid when the outside temperature undergoes steady periodic changes. The hour-by-hour heating and cooling loads calculated by using actual weather data, however, will give results that are quite different from this method.

It is now generally accepted that the Response Factor Method (7,8) is the only rational way to evaluate the heat conduction through a wall or roof of multi-layer construction under unsteady, non-periodic outdoor conditions. This algorithm has been adopted by most of the large energy analysis programs. To calculate the cooling (heating) load requires a rather laborious solution of energy balance equations involving conduction, convection, and radiation heat exchange between the room air, surrounding surfaces, infiltration and internal energy sources. If a space has m surfaces, there will be m equations governing the energy exchange at each inside surface at a given time. After these m equations are solved simultaneously with the governing equations of heat conduction and solar heat gain, the cooling (heating) load at that given time can be determined. This is one of the two algorithms described in the latest ASHRAE procedures (9,10). This fundamental approach in calculating the cooling (heating) load requires considerable computer time, especially if the calculations have to be performed 8760 times for annual energy estimates. This methodology is used in NBSLD (4) and the LOADS portion of the BLAST (11) energy analysis program.

The other ASHRAE algorithm for determining the cooling (heating) load is a simplified procedure known as the Weighting Factor Method. This method was developed by Mitalas and Stephenson (12) of the National Research Council of Canada. A study by Mitalas (13) shows that actual heat extracted from the space is considerably smaller than the heat gain calculated on the basis of a constant space temperature. This is due to the thermal storage effect of the building structure and internal furnishings. Therefore, in the Weighting Factor Method, two steps of calculations are involved. First, instantaneous heat gains or heat losses through the exterior envelope (walls, roof, windows and floor) of the building are calculated using the Response Factor Method. These heat gains (or losses) through the building envelope and heat gains from internal sources such as lights, equipment, and occupants, are then modified by the weighting factors to yield the cooling (or heating) load. Several sets of weighting factors were developed for the typical buildings of heavy, medium, and light structures for different types of heat gains by solving the fundamental heat balance equations. The Weighting Factor Method is valid as long as the weighting factors used exactly match the building structure under consideration. Generally, the building structures are not identical to those used to generate the weighting factors. Fortunately, slight deviation does not cause serious errors for estimating the annual energy requirements as long as the heat gain calculations are accurate. The Post Office program (5) and its subsequent enhancements, NECAP (14), CAL-ERDA (15,16), and DOE (17) use the Weighting Factor Method.

The system simulation is designed to predict the performance of the HVAC system response to the cooling and heating loads. The user must select the HVAC systems to be considered and must specify the various components and control features for each type of system. If the HVAC systems available in the program library do not meet the exact system or control feature desired, the user must select one that is thermodynamically similar to the one under consideration.

Procedures and algorithms for major HVAC systems and components have been developed by ASHRAE for quasi-steady-state simulations. Quasi-steady-state simulation refers to the steady-state operation at a certain hour, but it will be different at the next hour. It is essential that the dynamic characteristics of the building be considered in the calculation of the thermal loads, but the dynamic response of most systems is much more rapid than that of the building. Therefore, quasi-steady-state simulations of systems have been adopted.

During most of the operating hours, the central plant equipment operates under part-load conditions. All energy analysis programs use polynomial equations to describe the part-load performance of the equipment, and some of the mathematical models are oversimplified. Large energy programs use more sophisticated models which include performance data for the entire range of operating conditions that might be experienced during the year of operating conditions. These include corrections of equipment capacity, and energy consumption for different operating and weather conditions. Generally, the typical performance data are built into the mathematical model for each type of equipment. For specific equipment, the performance data must be supplied by the manufacturers.

Most of the ASHRAE calculation procedures and algorithms were validated during a four-year (1969-1973) field testing program sponsored by the TGER. Under this program, the Law Center Building at the Ohio State University Campus and its energy systems were simulated and extensively monitored. The computed building heating and cooling loads and the requirements of the energy systems and components were compared with measured data (18,19).

Currently, the Department of Energy is in the process of verifying and validating the DOE program which incorporates ASHRAE recommended and other algorithms all fully documented in the Program Manual (20). This effort is coordinated by the Los Alamos Scientific Laboratory (LASL). One phase of this validation effort will simulate seven existing buildings and compare predicted vs. actual energy requirements. The buildings under study are: single-floor office building; multi-floor office building; restaurant/cafeteria; hospital; retail/grocery store; school, and the National Security and Resource Study Center at LASL. Comparisons of various computer programs have been reported in terms of cost, availability, ease of use, as well as outputs (21,22). These comparisons to each other satisfy curiosity but do not raise the user confidence level of their accuracy. Widespread use of a program on numerous building types with comparison to actual energy measurements is needed to resolve this question.

AVAILABLE COMPUTER ENERGY PROGRAMS

There are approximately a dozen proprietary energy analysis programs (23,24) available to engineers and architects through computer service bureaus (see Table 1). Most of these programs, however, are not well documented and supported, so they are expensive to use. All of these programs claim ASHRAE literature to justify their algorithms and calculation procedures, but the lack of documentation and their proprietary purposes make them "black boxes." The energy programs that are completely "transparent" are those in the public domain.

Public energy analysis programs can be divided into two families depending on their cooling load calculation methods, namely, the heat balance method and the weighting factors method. Figure 2 shows the family lines of these programs. The NBSLD program developed by the National Bureau of Standards adopted the heat balance method, but it is a loads program, not an energy program. The U.S. Army Construction Engineering Research Laboratory (CERL) combined NBSLD with the Total Energy Plant Simulation (TEPS) program developed by the Computation Consultants Bureau (CCB) and their own system

TABLE 1

COMMERCIALLY AVAILABLE ENERGY COMPUTER PROGRAMS

1.	TRACE	THE TRANE COMPANY
2.	AXCESS	EDISON ELECTRIC INSTITUTE
3.	ECUBE	AMERICAN GAS ASSOCIATION
4.	ESP	AUTOMATED PROCEDURES FOR ENGINEERING CONSULTANTS
5.	MERIWETHER (ESA)	ROSS F. MERIWETHER & ASSOC.
6.	SCOUT	GARD, INC.
7.	SEE	THE SINGER CO.
8.	CCB	CONSULTANTS COMPUTATION BUREAU
9.	BUILDSIM	HONEYWELL, INC.
10.	MACE	McDONNELL DOUGLAS CORP.
11.	MEDSI	MECHANICAL ENGINEERS DATA SERVICES, INC.

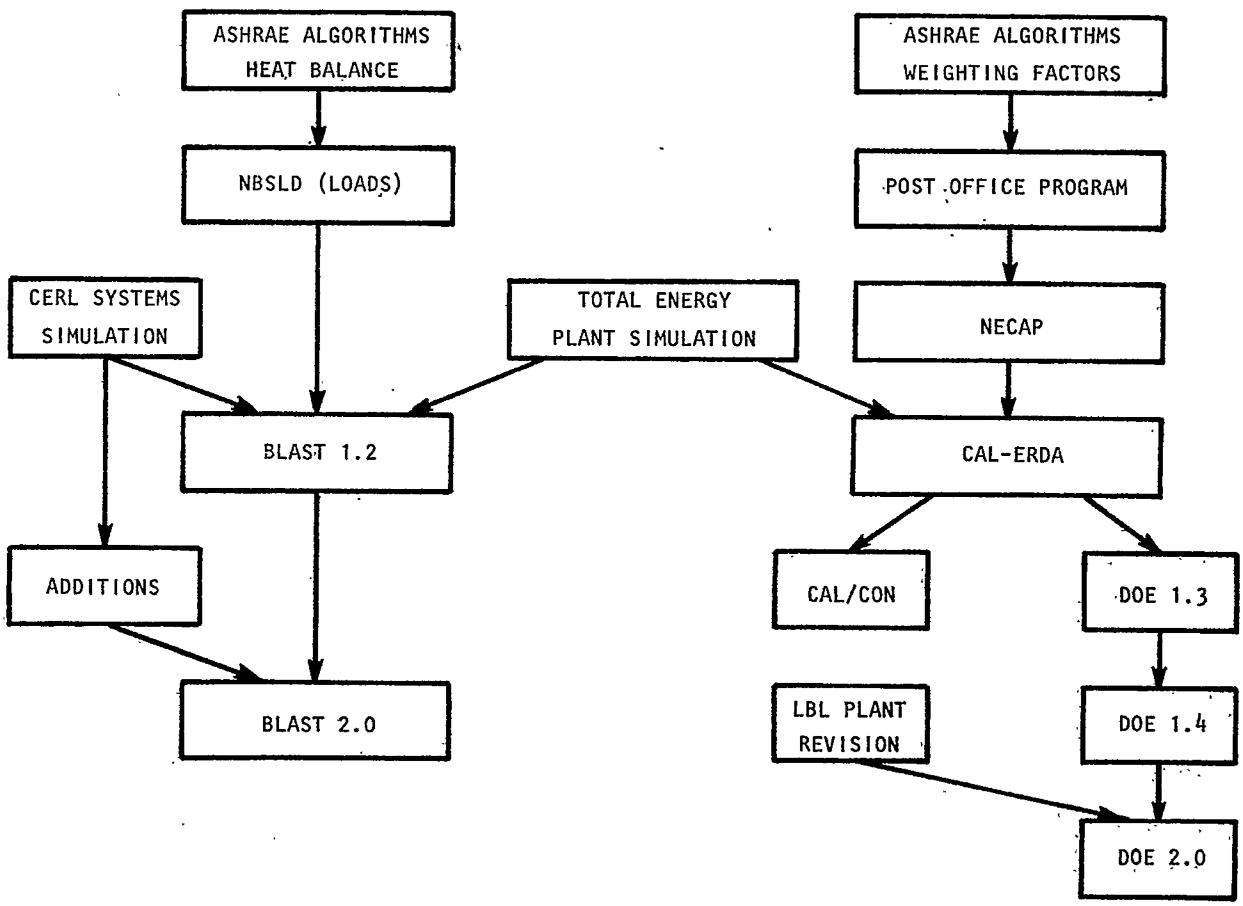

FIGURE 2: FAMILY TREES OF PUBLIC DOMAIN PROGRAMS

simulations to form a complete energy analysis program known as BLAST 1.2. Recently, CERL expanded the system simulations to include more HVAC system types and upgraded the BLAST program to the 2.0 level, which was released to the public on June 15, 1979.

The first public domain energy analysis program was developed by the General American Transportation Corporation for the U.S. Post Office. This program used the ASHRAE weighting factors method and was enhanced by the National Aeronautics and Space Administration (NASA) and renamed the NASA Energy Cost Analysis Program (NECAP). In 1976, Lawrence Berkeley Laboratory (LBL), Los Alamos Scientific Laboratory (LASL), and Argonne National Laboratory (ANL), with funding by the California Energy Commission (CEC) and the Energy Research and Development Administration (ERDA), joined with CCB and other consultants to significantly upgrade NECAP. They added the Total Energy Plant Simulation program, three HVAC systems and considerably improved the useability of the program by introducing a Building Design Language. This greatly modified NECAP program was then renamed CAL-ERDA. After receiving the final product from LBL, the California Energy Commission adopted the program as the official energy program for California and renamed it CAL/CON. During the same period, ERDA was changed to the Department of Energy and the same program was renamed DOE 1.3. LBL, with continued DOE funds, subsequently issued DOE 1.4 and has recently radically revised the central plant portion of the program in the DOE 2.0 version released June 15, 1979.

FUTURE IMPROVEMENTS

The ASHRAE recommended algorithms and calculation procedures represent the latest state-of-the-art for building energy analysis programs. These recommendations are continually being updated and modified as more research is accomplished in this area. It is not surprising, therefore, to find that formerly accepted calculation simplifications are now being re-examined and upgraded as DOE pours funds into their building energy conservation and solar application programs. Some of the areas that need improvement are:

1. Solar Calculations: Most programs use cloud cover modifiers in their weather tapes to compute the direct and diffused solar radiation based on the amount and type of clouds in the sky. Recently, Galloway of Lawrence Livermore Laboratory, Livermore, California, reported at the 14th Intersociety Energy Conversion Engineering Conference that there is less solar energy available in urban areas than had been previously estimated due to air pollution. He stated that the old method used to calculate the solar flux may overestimate the solar energy available in polluted urban areas by about 30%.

2. Daylighting Evaluation: Lighting loads in all programs use percentage of peak schedules to simulate reduced electrical loads at different times of day. Although illumination programs have been developed to design interior lighting systems, they have not been integrated into energy analysis programs to properly calculate electrical and HVAC system savings due to various daylighting schemes at windows.

3. Inter-Zone Exchange: The exchange of heat and air due to temperature and pressure differentials between adjacent building spaces is complex and difficult to analyze in a rational manner. The prediction of air transfers through building interior passages due to thermal and pressure gradients is not only significant to energy calculations but also smoke migration analysis.

4. Ground Heat Transfer: Most programs calculate the heat loss through slab-on-grade, and basement walls based on total surface areas and seasonal ground temperature. This assumes the ground to be an infinite sink at a constant temperature which results in overestimates of heat loss through these surfaces.

5. Evaporative Cooling: Most programs predict the performance of cooling towers on cooling equipment due to variations in outside dry and wet bulb temperatures, but are unable to properly calculate the process of evaporating water into an air stream of a HVAC system.

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