1997 ASHRAE Technology Award

Dudley Products includes office, laboratory and manufacturing space. The solution to the diversity in loads was 13 heating and cooling air-to-air heat pump zones. Six zones were created for the offices and seven zones for the manufacturing plant.

Total Systems Design Approach

By Harry Boody
Member ASHRAE

Dudley Products, Inc., an 85,327 ft^2 (7927 m^2) facility, consists of 33,305 ft^2 (3094 m^2) of offices and laboratories. It has 30 ft (9.1 m) ceilings in the spacious lobby, and a 52,022 ft^2 (4833 m^2) manufacturing facility with 22 ft (6.7 m) ceilings. These facilities produce a total heated and cooled volumetric space of approximately 1.5 million cubic feet (42 480 m^3). Our goals were:

- To produce a guaranteed, performance-based "Total System Design."
- To create a comfortable, energy-efficient "green" building.
- To apply *ASHRAE Standards 55-1992, 62-1989* and *90.1-1989* for the efficient use of energy and to produce a healthy work environment.
- To construct a model "Energy Efficient Facility" for engineering schools and others in the HVAC-related industry.
- To produce a project yielding immediate positive cash flow, making this project an excellent return on investment.

Prior to construction, detailed computer modeling was used to substantiate our system/component method of compliance. The building envelope's thermal transmission was greatly reduced. To ensure resistance to water vapor transmission, foil-backed drywall was specified with all joints scaled.

The two exterior brick walls of the manufacturing facility were erected with a 4 in. (102 mm) space filled with an environmentally safe (non-formaldehyde) R-20 liquid foam.

The entire roof system incorporated two 3-in. (76 mm) layers (R-5/inch) of water-resistant (recyclable) insulation board (R-30 total). All joints were staggered to minimize thermal short-circuiting.

Due to the building orientation and the high percentage of glass, clear heat mirror glass filled with krypton gas was used. This 1.125-in. (32 mm) thick glass system utilizes a heat seal and thermal break spacer and two

This project won in the category for industrial facilities or processes.

About the Author

Harry John Boody is founder and president of Energy Innovations by Harry Boody. He has earned a series of state and national awards, including two 1997 ASHRAE Technology Awards. He has been a member of the North Piedmont Chapter of ASHRAE since 1986. Boody specializes in the Total Systems Design Approach.

layers of clear film. It has a measured R-value of 9.0, and blocks 99.5% of the suns ultraviolet radiation.

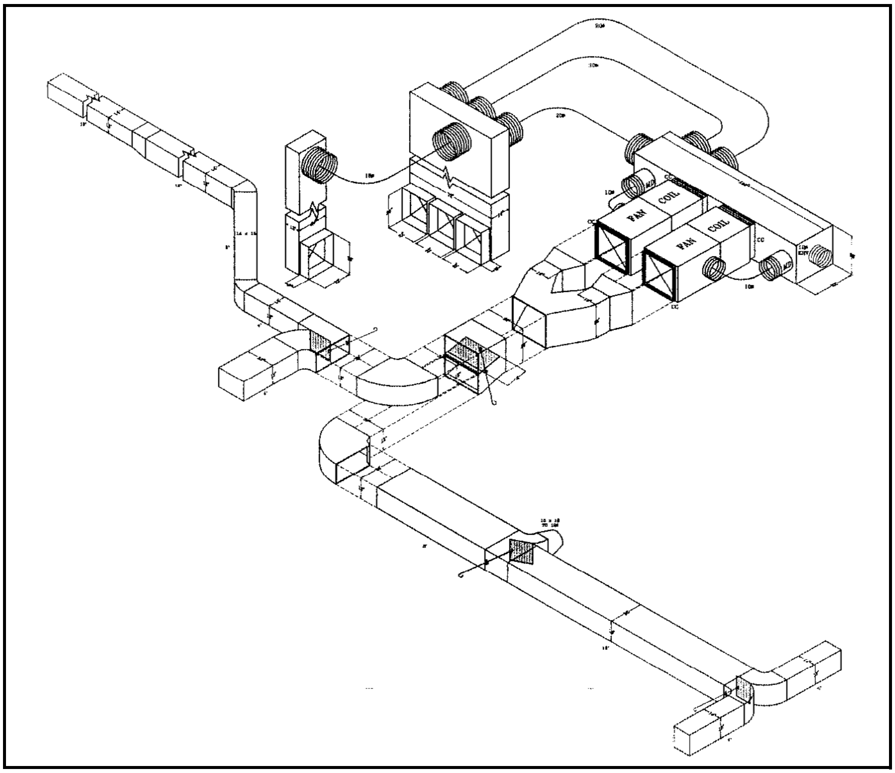
Realizing that the true performance of any window system is greatly affected by its metal framing, we thermally improved the metal frames by incorporating a poured, staked, and debridged true thermal break. We further reduced thermal bypassing by installing 1.5-in. (38 mm) diameter pliable foam rubber in and around all hollow spaces of the metal frames. Metal frames are typically installed uninsulated.

The Lighting System

In addition to controlling heat loss and gain by the improved thermal envelope, detailed analysis indicated that heat output and energy consumption from lighting could be reduced from 127.2 kW to 76.2 kW (174,114 Btu/h [51 033 W] less heat generated or 14.5 tons [51 kW] less air conditioning) without affecting the lighting quality.

Double wall switches control three T-8-32 watt electronic ballast lamps; the first switch controls one tube, while the second switch controls two tubes. Staging of light output proved feasible and cost effective due to the quality of natural daylight. PL fluorescent 58-watt units were specified instead of 150-watt incandescent down lights.

For the manufacturing space, a series of industrial lamps were specified utilizing hi/lo two-stage lighting that automatically controls light levels when there is no activity in an area. This provides additional savings of 238 Watts/fixture. All exit lights for the entire facility are 1.8-Watt LED fixtures as opposed to the typical 40-Watt exit lights.



Air handlers (drawing and photo) are tied together in parallel to create four stages of heating and four stages of cooling. This unit serves one of the six zones in the 33,005 ft^2 office.

One of the innovative aspects of this project (which is covered in the innovation criteria of this report) was the reduction of the heating design load from 1,594,500 Btu/h (467 348 W) to 938,430 Btu/h (275 054 W); a savings of 41.4%.

The cooling design load was reduced from 206 tons (725 kW) to 89 tons (313 kW); a savings of 117 tons (411 kW), or 56.8%.

A Primary Challenge

Even though the design loads were greatly reduced, adequate airflow to condition 1.5 million cubic feet (42 480 m^3) of space had to be maintained. This presented a challenge.

The “Maximum Power Transfer” theorem states: If one matches the source (HVAC system) to the design load (total thermal envelope and internal loads), maximum energy transfer will be achieved. If 89 tons (313 kW) is the worst-case design load, then the remainder (80%) of the year the building will operate with considerably less capacity.

Due to the diversity in loads, the solution was to create 13 heating and cooling air-to-air heat pump zones. Six zones were created for the offices and seven zones for the manufacturing plant.

To achieve optimum maximum load matching, we created four stages each of heating and cooling using dual-speed, high-efficiency heat pumps for each zone. To satisfy the large airflow requirement, we placed two high-volume fan/coil indoor air-handling units in parallel feeding each air distribution zone. Dual-speed outdoor heat pump compressor units were connected to each indoor fan/coil unit. Thus two compressors and two air handlers serve each zone.

The staging for load matching with maximum comfort is achieved as follows:

1. First stage cooling powers both air handlers and one outdoor heat pump running in the low-speed mode.

2. Second stage cooling activates the second outdoor heat pump also operating at low speed. (Anytime the system is operating in the low speed-cooling mode; each air handler is bypassing the required amount of airflow around the cooling coils to achieve maximum dehumidification.) The air distribution system always delivers the full airflow to each conditioned space regardless of high or low-speed compressor operation.

3. Third stage cooling switches the first outdoor heat pump from low speed to high-speed operation and closes the corresponding air bypass.

4. Fourth stage cooling switches the second outdoor heat pump from low speed too high speed and closes the second coil bypass.

In the heating mode, the same process is followed except all air/coil bypasses remain closed to extract maximum Btu's off the heating coils. The low-velocity air distribution system design does not realize the lower discharge temperatures so comfort is not affected.

To date, the 33,305 ft^2 (3094 m^2) office section of this facility is operating in the low-speed capacity mode an average of 85% of the time Averaged monthly costs for heating and cooling are $794.10 (13,235 kWh @ $0.06/Kwh).

The 52,022 ft^2 (4833 m^2) manufacturing facility averages 37% of the time in the low-speed capacity mode. This is due to the high internal heat gain from equipment. In the winter, this heat offsets heating costs. Average monthly costs for heating and cooling are $1,513.63 (25,227 kWh @ $0.06/Kwh).

New technology was adopted for the Energy Recovery Ventilation System. As stated earlier, indoor air quality with comfort and energy efficiency were priorities.

Energy Recovery Ventilation

The Energy Recovery Ventilation equipment incorporates heat pump and heat pipe technology together. Its theory of operation is to pass the outdoor air (filtering it with high-density ASHRAE rated bag filters) through heat pipe coils and heating/cooling coils (dependent upon mode) and deliver this preconditioned air through the main air distribution system to each heat pump zone. The exhaust air is returned through all restrooms (eliminating the need for restroom exhaust fans) and prefiltered before crossing the exhaust side heat pipes and refrigerant coils.

Air filtration, proper distribution of airflow, and controlled infiltrations of air are significant factors in human comfort. Dudley Products has noted:

• Increased worker productivity and reduced absenteeism.

• An indoor environment of 73°F (22.2°C) provides an "at home" feeling of comfort due in part to combining large quantities of low-velocity (450 fpm or 2.61 m/s) airflow with downsized capacity.

• Excellent dehumidification due to equipment operating longer at steady state because of the staging instead of short cycling on and off.

• 70°F (21.1°C) winter indoor design temperature appears to be the temperature of choice. Low-velocity air movement improved the indoor comfort (at a lower temperature setting) by reducing the draft effect associated with higher velocity air distribution.

It is interesting that earlier this year, the 2000-CFM (9444 L/s) Energy Recovery Ventilation (ERV) system, which serves the main office areas on levels one and two, cycled off due to a broken fan belt. According to the Energy Monitoring System, this unit was out of service for about two weeks while awaiting the fan belt replacement. The maximum CO_2 level reached was 1285 ppm. As soon as the ERV was brought back on line, the CO_2 level dropped to less than 500 ppm in less than one hour.

Airflow Ventilation

More than 50 high-density +90% ASHRAE rated (low static) air cleaners are filtering airflow throughout the entire building. All airflow is filtered before entering the return air ducts resulting in cleaner ductwork. (The contract cleaning service has commented on several occasions that the dust level is considerably less than in other buildings.) Carbon dioxide levels have measured a remarkably low 400 to 485 ppm (less than 1000 ppm is the acceptable EPA level.) Even though the manufacturing plant is attached directly to the office section, odor-free control has been achieved.

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The "micro lab" in this facility requires special ventilation of source contaminants. Airflow entering this room is supplied through a 2-by-4 ft (.61-by-1.22 m) HEPA fan filter from the main HVAC system. The return air is transferred through another HEPA fan filter and exhausted outdoors.

Achievable Results

This building had already been designed; the contractor selected and bids awarded when the owner commissioned our firm to redesign the thermal envelope, lighting and HVAC systems. The challenge was to take a Total Systems Design Approach and produce a performance based, energy accountable building, (guaranteeing energy consumption) with excellent comfort and indoor air quality while yielding an immediate positive cash flow by saving more money on monthly utility bills than the cost in increased mortgage payment. Obviously, this project required an extensive quality control program to achieve the desired results.

Despite the absence of enforced industry standards (at the time), and having to work with (or around) a skeptical architect and general contractor, we achieved our desired results . . . a 1.5 million cubic foot (42 480 m3) building which is comfortably conditioned with only 89 tons (313 kW) of HVAC capacity using four stages of heating/cooling for constant "load matching." No electric strip heating is required.

See Boody, Page 68

Advertisement in the print
edition formerly in this space.

Boody, From Page 66

Data Collecting

To further our understanding of the operating characteristics of this building, a data collection system was installed. The energy management monitoring and data collection systems are supported by two separate computers. Up to 25 million samples can be stored for historical archiving. The historical operating data has proven to be a valuable tool for trouble-shooting equipment problems and fine-tuning the energy systems. It is our goal to supply engineering schools (through the Internet) this "real-world" database for class-.1 study to provide a clear example the Total Systems Design Approach. The building incorporates a user-friendly energy management and monitoring. Data are accessible to anyone with a pass code. Further pass codes are required to manipulate preprogrammed functions.

The O&M of this facility was designed for simplicity. Filters are changed annually for the office section and bi-annually for the plant or when the energy monitoring system detects a pressure drop across a filter greater than 0.25 inches of water. Increased lamp and ballast life reduces maintenance and upkeep costs on the lighting system. The building is under contract with a preventive maintenance service that understands the importance of systems performance.

Return on Investments

Even with $261,414 in incremental cost increases and the 8.5% interest on borrowed money, this project resulted in an immediate positive cash flow payback.

The yearly mortgage payments over the next 15 years (principal plus interest) are $2,574.25/month. The first year energy and interest tag savings are $3,320.78/month, yielding a net positive cash flow of $746.53/month [$8,958 the first year].

This extra investment in energy-saving features, principal plus interest, is projected at $463,364. Assuming a 3% annual energy cost increase, the total energy and tax savings are projected to be $682,566. The projected 15-year total positive cash flow (net profit) will be $219,201 or a 12.2% pre-tax return on investment.

This project was achieved without government aid or grants showing energy conservation through private enterprise is a good investment.

This Total Systems Design Approach produced improved comfort, efficiency, and indoor air quality. Overall operating costs were reduced approximately 41% and the HVAC equipment tonnage was reduced approximately 57%. Therefore, this "green building" consumed fewer natural resources are consumed for both installation and operation and less refrigerants were required, substantially reducing the environmental impact of this project. ■

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