Right-Sizing Laboratory HVAC Systems

Using measured equipment-load data to avoid oversizing and minimize simultaneous heating and cooling, reducing initial and life-cycle costs

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Editor's note: This is Part 2 in a two-part series. Part 1 was published in September.

Underestimation of equipment-load variation across laboratory spaces exacerbates the problem of simultaneous heating and cooling, particularly with systems that use zone reheat for temperature control.

Figure 5 shows equipment loads measured in 15-min intervals in various laboratory spaces in the UC Davis (University of California, Davis) building discussed in Part 1 of this article. For most spaces, the maximum load is less than 6 w per square foot; for a few, it is 6 to 10 w per square foot, while for one, it is about 17 w per square foot.

One or two laboratory spaces having comparatively high equipment loads is fairly common. A problem arises when all spaces are served by a single air-handling unit (AHU) with zone reheat coils for temperature control (a widely used strategy). The high-intensity spaces drive supply-air temperatures and flows to handle their equipment loads. As a result, the other spaces have to use reheat to maintain desired temperatures.

ENERGY-USE ANALYSIS

To analyze the increase in reheat-energy use arising from equipment-load variation, several parametric energy simulations were conducted using DOE-2.2

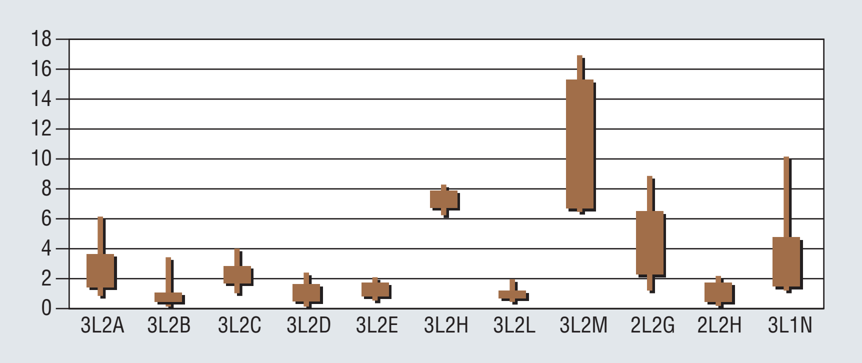

FIGURE 5. Equipment loads measured in 15-min intervals. The top and bottom edges of the boxes represent the 99th and first percentiles of the measurements, respectively, while the ends of the upper and lower lines represent maximum and minimum, respectively.

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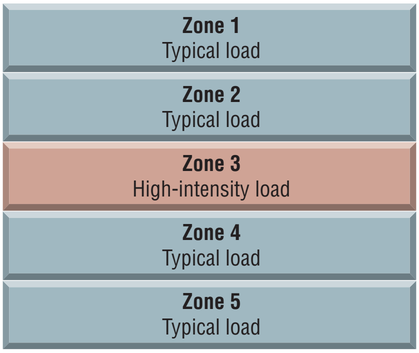

FIGURE 6. Simulation model used to analyze the energy impact of load variation. Zone 3 is about 12.5 percent of the total area.

energy-simulation software. The simulation model consisted of five laboratory spaces served by a single AHU (Figure 6). To eliminate envelope-related load variations across the spaces, boundary conditions were assumed to be adiabatic. The lighting and occupancy load profiles were identical.

Each parametric case consisted of two simulations:

- Load variation—one zone with a "high-intensity" equipment-load profile, the remaining zones with a "typical" load profile.
- Uniform loads—all zones with the same equipment-load profile, which represented an area-weighted average of the "high-intensity" and "typical" load profiles.

The simulated load profiles are illustrated in Figure 7. Total equipment load in any given hour is identical for both, as are all other parameters. Thus, energy impacts of load variation can be isolated and analyzed.

The base-case model was a variable-air-volume (VAV) system with hot-water reheat, a water-cooled chiller plant, and a natural-gas boiler. HVAC-component and system efficiencies were consistent with good practice. None of the HVAC-component and system parameters was varied. The minimum outdoor-air ventilation rate was 1 cfm per square foot.

Figure 8 shows base-case source-energy-use intensity in three climates in the United States: San Francisco; Washington, D.C.; and Atlanta. The increase in total source-energy intensity attributed to load variation ranged from 10 percent in San Francisco to 14 percent in Atlanta. An analysis of the simulation results showed that the bulk of this was attributed to additional heating. The increase in heating-energy use attributed to zone reheat coils was 48 percent in Washington, D.C.; 50 percent in San Francisco; and 68 percent in Atlanta.

In addition to location, increases in reheat-energy use were shown to vary by ventilation rate. Higher ventilation rates increased total energy use. However, as ventilation rates increased, heating and cooling requirements were less "internal-

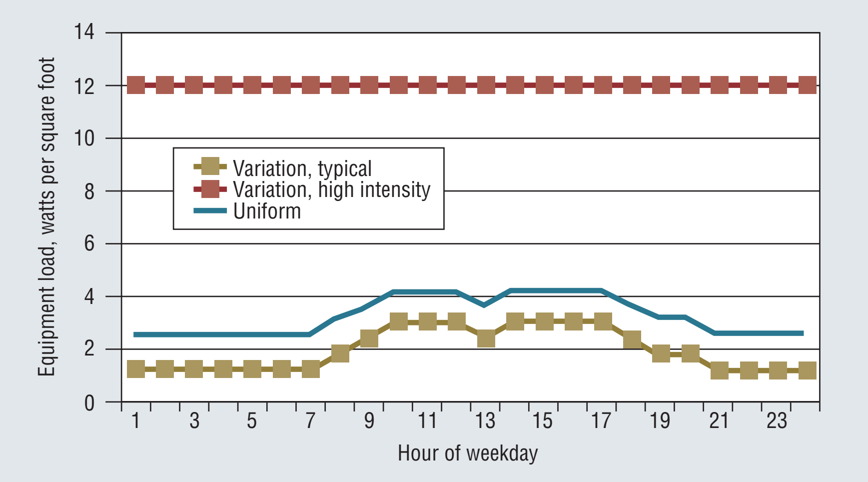

FIGURE 7. Simulated equipment-load profiles.

"load-driven" and more "ventilation-driven," reducing the impact attributed to load variation. Figure 9 shows that when the ventilation rate was doubled to 2 cfm per square foot, the percentage increase was 7 percent (vs. 11 percent for 1 cfm per square foot). At 3 cfm per square foot, the impact of load variation on reheat-energy use was minimal.

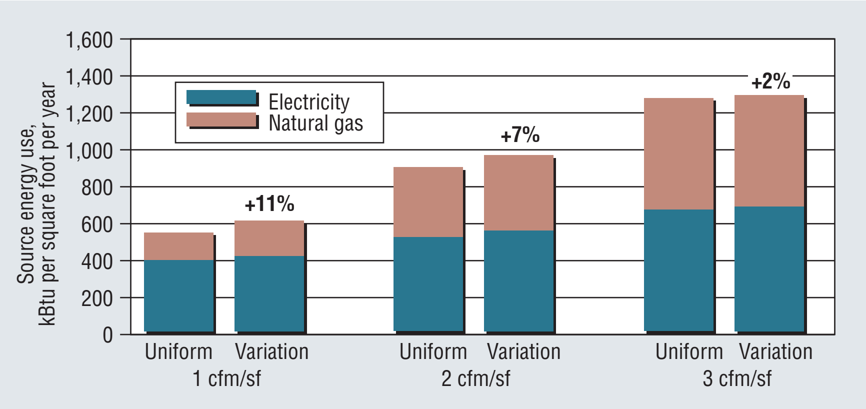

FIGURE 9. Sensitivity analysis of source-energy-use intensities for different ventilation rates. All results are for Washington, D.C.

Another factor shown to affect increases in reheat-energy use was degree of load variation. In the base case, the high-intensity load was 12 w per square foot, while the peak of the typical load profile was about 3 w per square foot. When the differential was reduced, the increase in reheat-energy use fell. For example, when the high-intensity load was halved to 6 w per square foot, the increase in reheat-energy use dropped from 10 percent to 7 percent in San Francisco and from 11 percent to 6 percent in Washington, D.C. (Figure 10)

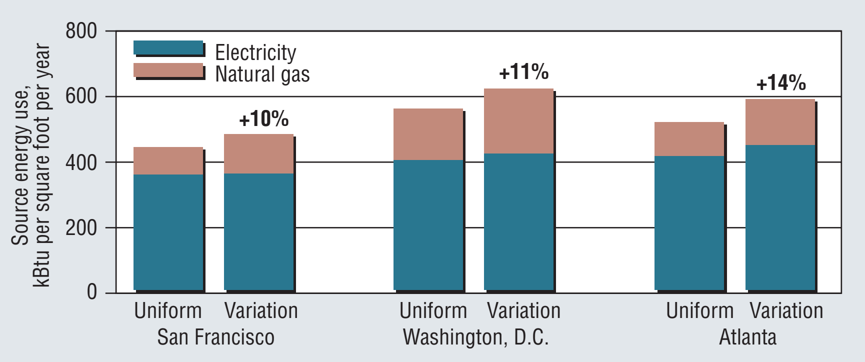

FIGURE 8. Base-case source-energy-use intensity in three U.S. climates: San Francisco; Washington, D.C.; and Atlanta. The percentages are the increase in total source energy relative to the uniform-load simulation for each case.

Although the HVAC controls were assumed to be working properly, experience indicates that they often deviate from design intent. As a result, energy use attributed to simultaneous heating and cooling can increase dramatically.

MINIMIZING REHEAT-ENERGY USE

If reheat-energy use is to be minimized, first, it must be properly assessed during design. Labs21 (Labs for the 21st Century) modeling guidelines,[12] which are used in conjunction with ANSI/ASHRAE/IESNA Standard 90.1-2001, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, specify a standardized approach to incorporating load variation into simulation models used for compliance and benchmarking.

Figure 11 shows four options for mitigating reheat-energy use:[13]

- *Dual duct with terminal heating* (DDTH). This system consists of two separate variable-volume supply-air streams—one tempered and one cold. Labs with high cooling requirements draw air primarily from the cold-air stream, while others draw air primarily from the tempered-air stream.
- *Zone cooling and heating coils* (ZC). This system consists of a single tempered supply-air stream, with the primary cooling and heating provided by zone heating and cooling coils.
- *Ventilation air with local fan coils* (FC). In principle, this is similar to the ZC system, the difference being that heating and cooling are provided by

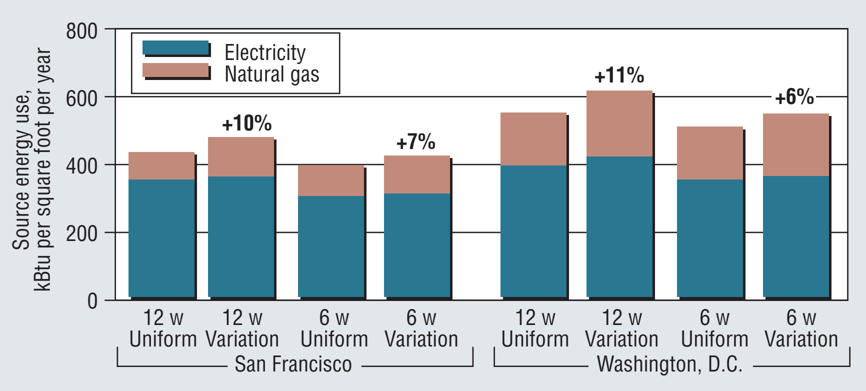

FIGURE 10. Sensitivity analysis of degree of load differential between high-intensity space and typical zone.

fan-coil units, rather than coils directly in the ventilation-air stream.

- *Ventilation air with radiant cooling* (RC). This system also features a tempered supply-air stream for ventilation. Space cooling is provided by radiant panels or chilled beams, while space heating is provided by zone heating coils located in the supply-air stream.

Measurements from various laboratories indicate that peak equipment load tends to be overestimated greatly. Further, the data show significant load variation between spaces.

While the costs of constructing these systems may be higher and the maintenance requirements more decentralized than those of conventional VAV systems with reheat, the energy savings may result in lower overall life-cycle cost, depending on the cost of energy and other contextual factors. Integrated design can minimize construction-cost premiums. Morehead[13] documented the case of a 90,000-sq-ft laboratory in which the incremental cost of a DDTH system was only about $16,400, which amounted to about 18 cents per square foot. In load-driven labs, ZC, FC, and RC systems require less space for ducts because the ducts are for ventilation air only. Also, these systems provide more flexibility by adding cooling capacity to spaces.

In many parts of the United States, dehumidification requirements also contribute significantly to reheat-energy use. In those places, DDTH, ZC, FC, and RC systems should incorporate technologies such as energy-recovery wheels and wrap-around heat-pipe coils.

In any of the system types described above, continuous commissioning and diagnostics can aid the identification of zones with excessive reheat.

CONCLUSION

Measurements from various laborato-

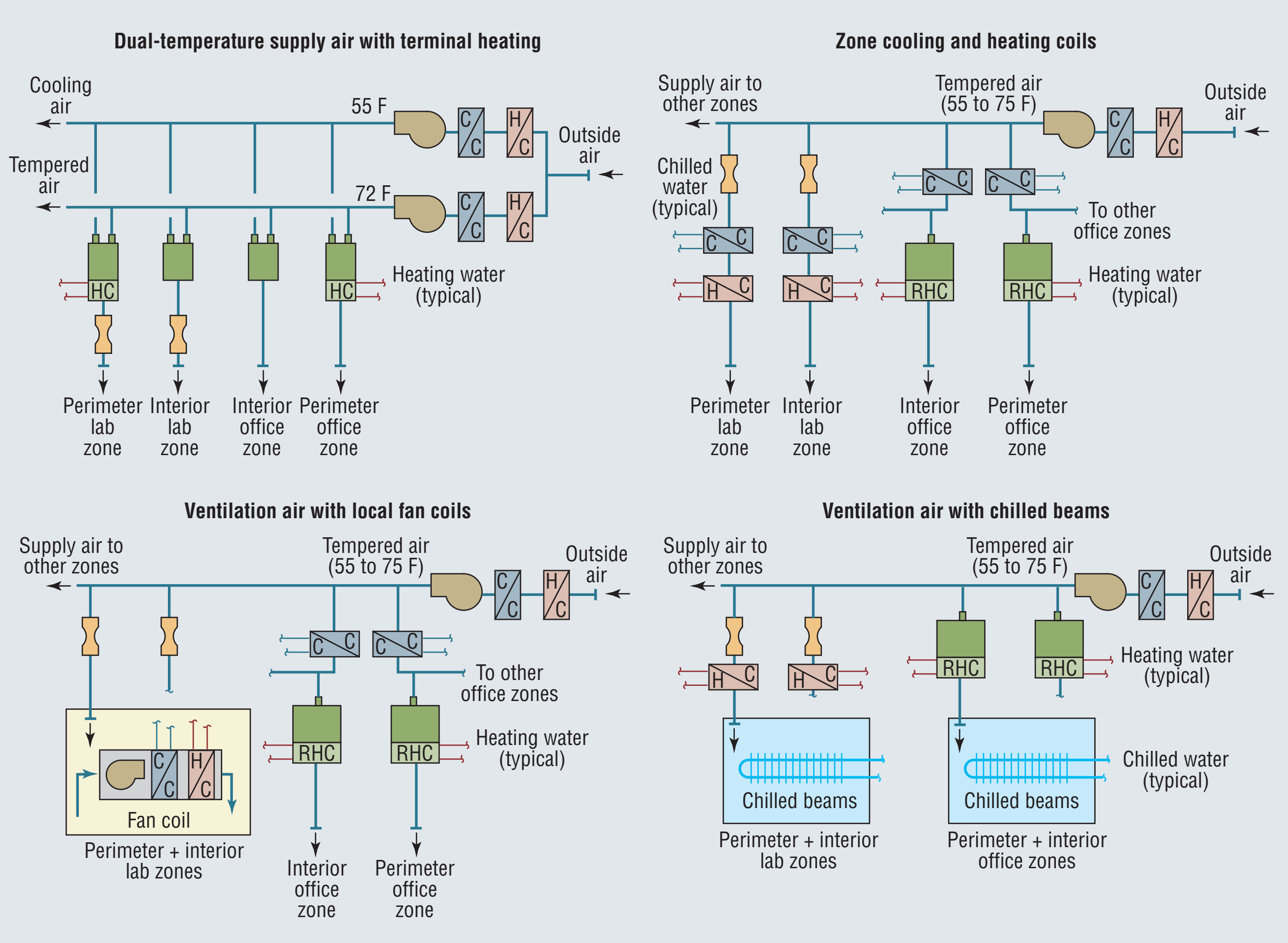

FIGURE 11. HVAC systems designed to minimize reheat-energy use attributed to load variation between zones.

ries indicate that peak equipment load tends to be overestimated greatly. Further, the data show significant load variation between spaces. Simulation analysis demonstrates that this can result in simultaneous heating and cooling and excessive energy use in VAV reheat systems.

In laboratory HVAC design, measured equipment-load data from comparable facilities can support system rightsizing and optimization, minimizing simultaneous heating and cooling and saving initial construction costs and life-cycle energy costs. The cost of the measurements is far outweighed by the potential reductions in HVAC-system size and energy use.

To better evaluate the energy efficiency of HVAC systems, load variation must be accounted for accurately in energy simulations conducted during design.

The cost of the measurements is far outweighed by the potential reductions in HVAC-system size and energy use.

Although this article focused on laboratories, its lessons may apply to other complex buildings, such as data centers, cleanrooms, and hospitals, in which equipment loads are high and variable and for which measured data is lacking.

ACKNOWLEDGEMENT

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REFERENCES

12) Labs for the 21st Century. (2004). *Laboratory modeling guidelines using ASHRAE 90.1* (v. 1.0). Available at: http://www.labs21century.gov/pdf/ashrae_draft2.pdf

13) Morehead, M. (2003, October). *The problem with single-duct VAV: The built-in inefficiency of a common lab HVAC system*. Presented at the Laboratories for the 21st Century Annual Conference, St. Louis.

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