Art or Science?

Thermal Zoning For HVAC Design

BY BRIAN A. ROCK, PH.D., P.E., FELLOW ASHRAE

A novice is often surprised that the HVAC system types and thermal zones must be selected before detailed load or energy calculations can be performed. Electrical-power systems engineers determine the electrical loads before making equipment decisions, and structural engineers find their “live” and “dead” loads long before selecting their structural elements, don’t they? However, for HVAC design, as well as for energy-use modeling, a building’s performance is dependent on the HVAC systems and how spaces interact. Therefore, load and energy calculation software need these characterizations as input.

Making good systems and zoning decisions early improve acceptability of projects, while poor decisions lead to, at times, discomfort in spaces that don’t have thermostats, or possibly reduced indoor air quality. Energy consumption can be higher or lower with suboptimal decisions made so early in the design process.[1,2] This article defines and discusses thermal zoning for HVAC system design, and the factors affecting zoning decisions.

Spaces within buildings have varying thermal loads. To maintain the desired indoor temperature and humidity under transient sensible and latent heat gains and losses, these spaces need HVAC equipment with different capacities and separate control loops. For example, in many temperate climates it is common, during the fall and spring seasons, that one side of a building requires heating while another requires cooling. Or two similar, adjacent offices may require different levels of heating or cooling because one office is densely occupied while the other is not. Ideally, every space in a building would have a separate HVAC system.[3] Such an approach is often cost-prohibitive, so compromises must be made.

Core spaces are those on the interior of the building, with little to no exposure to the outdoors except via ventilation. Core spaces on the top floor of a building do have heat gains and losses via the roof and any skylights, and the lowest-level core spaces do exchange heat and moisture with the soil, or if exposed, the air beneath. *Perimeter* spaces interact strongly with the outdoors, and,

Brian A. Rock, Ph.D., P.E., is an associate professor for architectural engineering at the University of Kansas, Lawrence, Kan.

due to solar energy penetration, are typically defined as being within 15 ft (4.6 m) of a window, or less if a room is narrower; the 15 ft depth assumes the typical office ceiling height of about 9 to 10 ft (2.7 to 3 m), and should be deeper for spaces with taller windows. Once the core and perimeter spaces are identified, next is to determine if any or all can be grouped together for HVAC purposes.

What is Thermal Zoning?

The online, open-access *ASHRAE Terminology* web page[4] states that a *zone* is "(1) a separately controlled heated or cooled space. (2) one occupied space or several occupied spaces with similar occupancy category, occupant density, zone air distribution effectiveness, and zone primary airflow per unit area. (3) space or group of spaces within a building for which the heating, cooling, or lighting requirements are sufficiently similar that desired conditions can be maintained throughout by a single controlling device."

The last printed version of *Terminology*,[5] published in 1991, defined thermal *zoning* as the "1. division of a building or group of buildings into separately controlled spaces (zones), where different conditions can be maintained simultaneously. 2. practice of dividing a building into smaller sections for control of heating and cooling. Each section is selected so that one thermostat can be used to determine its requirements."

ASHRAE's five "load calculation manuals" (LCMs) are somewhat surprisingly almost silent on thermal zoning, with the first LCM, the 1979 "bumblebee book" by Rudoy and Cuba, having a definition for zones similar to the second definition from the 1991 *Terminology* book.[6]

For this paper's HVAC-design intent, *thermal zoning is the design-process of grouping spaces together that have similar HVAC needs*. As compared to having a separate system for each space, the purpose of zoning is to reduce the number of HVAC systems or subsystems to reduce initial cost while still maintaining comfort. It is also possible that the total equipment capacity can be reduced, too. For a particular project, defining more instead of fewer thermal zones implies more complexity and higher construction cost, but hopefully improved indoor conditions at times in more of the occupied spaces.[7,8] Defining fewer zones instead implies lower initial cost, but more hours per year of suboptimal conditions in more spaces. For energy modeling purposes, zoning is to divide a building into parts that respond fairly similarly; their zones may or may not be the actual HVAC zones because a proposed building has yet to be fully designed or to simplify an existing building to obtain modeling results more rapidly. The "Energy Estimating and Modeling Methods" chapter of the *ASHRAE Handbook* gives more information on zoning for that purpose. The chapter also includes a brief literature review toward automating zoning decisions, but states "a truly automated, one-size-fits-all approach remains to be developed."[9]

So is the process of thermal zoning currently an art,[1] or is it a science? The Merriam-Webster online dictionary's first definition of *art* is a "skill acquired by experience, study, or observation, e.g., the art of making friends."[10] For *science*, its fourth definition is "a system or method reconciling practical ends with scientific laws, e.g., cooking is both a science and an art." If zoning is a science, the ultimate goal may be to automate all HVAC design zoning decisions via software, while, if an art, removing all human involvement would likely yield doubtful results in many cases.

Poor zoning decisions are responsible for some comfort problems in buildings. However, once a building is completed, it is often difficult to make significant changes to the zoning because the installed equipment may not be highly flexible.[8] Recirculating constant air volume (CAV) systems with slightly questionable zoning tends to generate few complaints due to their consistent mixing provided by recirculation, but at the cost of high fan energy use. Variable air volume (VAV) systems are more sensitive to zoning decisions due to reduced airflow rates at most hours; cold air-distribution systems, with their still lower flow rates and inter-zonal mixing, are even more vulnerable to poor zoning choices. With overhead VAV and many underfloor air-distribution systems, correcting a zoning problem, or adapting for a change of use, can often be accomplished by dividing the branch ductwork, adding a terminal unit, and installing another local controller to create an additional zone. Access to the branch ductwork via suspended ceilings or modular raised floors improves the ease of making such a change.

Thermostats

While it is possible for a thermal zone to have multiple temperature, humidity, or air quality sensors in various places, by far the most common is to have only one device in one location, the most common being wall-mounted and for dry-bulb temperature only. For analog control systems, this temperature sensor is part of a thermostat, aka a "T-stat," that controls the operation of the attached terminal unit, air handler, or zone pump, as well as usually allowing adjustment of the setpoint temperature by the occupant. For digital systems such in-room devices are often just sensors, but some have system adjustment capabilities, too. All are called thermostats here for convenience.

For a thermal zone that includes multiple spaces, only one will have the zone's thermostat. The designer needs to make this choice, and to show on the mechanical plans where the T-stat should be placed. Typically the symbol used is a circled-T. When deciding where to put the thermostat, seek the zone's space that has controlling interest, for example in a classroom instead of its attached storage room; deciding between multiple offices is more challenging, and is discussed later. If the designer determines that a single sensor won't provide acceptable comfort in the multiple rooms of a zone, then either the rooms can be separated into more zones, or a control system that allows multiple sensors, and appropriate control sequences, can be specified to reduce but not eliminate a problem. A past attempt was to put the sensor in the return duct after the confluence of airflows from the zone's rooms, but occupants were typically annoyed by the lack of a visible thermostat.

Where one of these devices is placed in a space is important for the acceptability of a thermal zone. Comfort complaints can occur at times if a thermostat is placed on an exterior wall, on a high mass wall, in direct sunlight, or in a location with obstructed room air circulation such as in a corner, for example. Also consider furnishings such as markerboards and other interferences when specifying T-stats' locations in rooms, as well as accessibility issues.

Factors Affecting Zoning Decisions

When addressed elsewhere,[e.g., 1-3,6-9] a discussion of thermal zoning typically includes only a few of the following effects. However, other, sometimes competing, factors must be considered as well. Experience is very helpful, so a new HVAC designer's zoning abilities should improve with time.

Solar Exposure

The solar heat gains through windows, and to a lesser degree through opaque materials, will have a large effect on a space's conditioning needs. A space with mainly large easterly facing windows or glazed doors will have their maximum, "peak" solar-gains in the morning, where an otherwise-the-same, but west-facing space should peak in late afternoon. Horizontal surfaces, such as flat roofs and many skylights will often have peak solar heat gains at midday. Sloping surfaces require closer study, but may have much higher peak solar heat gains per unit area than equivalent vertical surfaces, for example. Various high-performance windows and external shading devices can reduce the influence of solar energy on zoning decisions, but solar gains will likely remain a large factor.

Construction of the Enclosure

In addition to the windows' materials, the thermal resistances of each space's exterior walls and its roof, if any, must be considered. A super-insulated living room will not respond similarly to a poorly or uninsulated enclosed porch that is adjacent to it, for example. For a well-insulated wall or roof, the order of the materials in each, e.g., where the primary insulation is versus any masonry, will have some effect, too, on the dynamic response of the space to changes in outdoor or indoor conditions.

Mass

All building materials, finishes, and furnishings have mass that store and release heat and thus affect how spaces respond to heat gains or losses. For HVAC load and energy calculations, normally only the largest, most easily characterized masses are considered, e.g., the walls and floors. Historically, before transient analyses, only the masses that received direct sunlight were considered, so typically were only the floors within 15 ft (4.6 m) of the exterior. However, improved models and increased computing capacity have allowed many more "thermal masses" to be included. Spaces are still often categorized early as low (e.g., wood-framed), medium (light steel), or high (concrete/masonry) mass to characterize their responses. Such should be considered in zoning decisions, e.g., where a light room is next to one with high mass. The low mass room will likely warm and cool much faster than the high mass one, for example, when a wood-framed addition is made to a masonry building.

Internal Loads

People, lights, and equipment are the internal heat gains; not only their magnitudes but also their schedules in each space are important in zoning decisions. For example, two auditoria or classrooms may otherwise be very similar, but their times-of-use may be significantly different. If linked to form one zone, only one room will get the thermostat. That room should be comfortable, but the other won't at times, e.g., when it is in full use but the controlling room is unoccupied. The second room will get warm and maybe stuffy. The reverse situation, where the controlling room is in high use but the second is only lightly loaded, the second room will become cool and possibly over-ventilated. Instead, consider making the rooms separate thermal zones.

Use, and Ventilation Needs

Ventilation rates for spaces should be determined via their intended use and ASHRAE Standards 62.1 or 62.2. However, with all-air HVAC systems, the flow rate of outdoor air for each space is combined with those for other spaces attached to the same air handler. So spaces with similar outdoor air needs should be grouped together, and the standard's multiple spaces equation employed to determine the optimal ventilation rate when using 62.1's Ventilation Rate Procedure. With demand-controlled ventilation, where the ventilation rate at the air intake is adjusted via measurements of trace gases in the zones, for example, too few air handlers may result in excessive ventilation in some zones due to the worst zones' behavior. Placing high-occupancy spaces on their own air handlers may be desirable from energy and humidity-control perspectives too.

Infiltration

In typical U.S. design practice, unless active neutral air pressure management is employed, designers choose to slightly positively pressurize their commercial buildings. This is done to eliminate, or at least minimize infiltration of unconditioned air into the perimeter spaces. Certain spaces, such as conditioned garages with large overhead doors, or entrance-areas with frequently used exterior doors, can easily lose this pressurization and thus have greater conditioning needs relative to a better-enclosed neighboring space. As is commonly observed, even having operable windows can cause comfort problems when misused by occupants. When otherwise similar, if one perimeter room has many or large operable openings and another has none or few, consider if the particular building's occupants can use those large openings wisely; if such cannot reasonably be concluded, consider zoning the spaces separately.
In North American housing, buildings are typically not pressurized, and, at times, are depressurized by exhaust fan operation thus increasing infiltration to exterior spaces. For multistory housing, the stack effect can lead to significant thermal discomfort, especially on the higher floors. Zoning residences, at least floor-by-floor, often improves comfort and may improve energy efficiency, too.

Ground Contact

Except for a partially above-ground story such as a walkout basement, fully below-grade spaces have no direct exposure to the outdoor air. They do transfer heat and moisture with the soil through their walls, the lowest level floor slab, and their foundations. As such, their spaces' conditioning needs are not very dependent on cardinal direction, and, if their exterior walls are insulated reasonably well, often both perimeter and core spaces can be combined within a particular below-grade zone. In cold climates these zones can get quite cool when unused, so provide heating and possibly humidification capacity for them. In cooling seasons, below-grade zones can need dehumidification even when naturally at acceptable temperatures.

Comfort Goals

Depending strongly on the climate and the desires of a particular client, most regularly occupied spaces will need systems with heating, humidifying, cooling, dehumidifying, and significant filtration capabilities. Neighboring spaces, such as warehouses, storage rooms, some restrooms, kitchens, or laundries may need or get only heating capacity and minimal air filtration, for example. Putting these other spaces on different zones with simpler systems is often appropriate. Or if using a "primary air-secondary air" or dedicated outdoor air (DOAS) system, where the terminal units provide much or all of the heating or cooling at the zone level instead of centrally, include only the relevant coils for each zone.

Setpoints and Setbacks

Zoning decisions can even be affected by desired setpoints, for example if one space in a data center needs to be much cooler than another of its spaces. Similarly, in many buildings, small information technology (IT) rooms with servers and routers may need cooling year-round, where neighboring spaces need heating at times. Additionally, for example in a small manufacturing facility with an attached front office, the air-conditioned production floor may have certain days of nonuse, and thus significant temperature setbacks can be employed, while the office space is still occupied, or vice-versa.

Multiple Tenants

The U.S.'s Public Utility Regulatory Policy Act (PURPA, 16 U.S.C. §2625(d)) of 1978 required, with exceptions, separate electric metering in new buildings with multiple units, and thus these buildings' tenants should have different, non-interconnected HVAC systems. People also want their own control. Ventilation needs vary, and HVAC airflows between tenants' units should be avoided for health, odor control, as well as fire safety reasons. Provide separate zones, and systems, too, for shared or fully public areas of multi-tenant buildings and meter these systems to the building's owner; the cost of such is to be recovered through the tenants' rent.

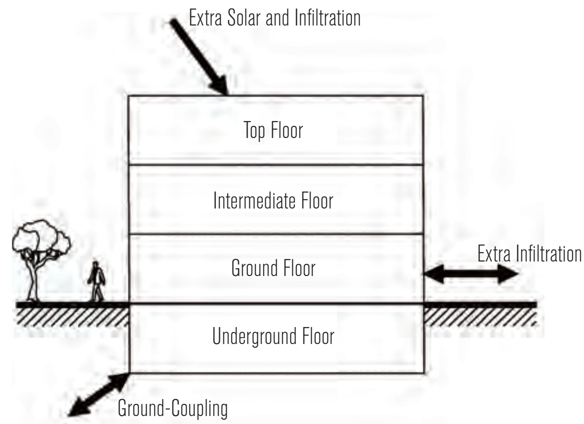
Cost and Expectations

The last factor, but not least by far, is the financial resources of the owner. Building-projects are typically classified, for preliminary HVAC design purposes, as low, medium, or high initial construction cost. At the upper end, highly controllable systems with liberal zoning choices are appropriate, but most commercial projects, at least in the U.S., are toward lower cost. Spending more initially, if done wisely, can payback many times over monetarily or via improved occupant satisfaction, so it is worth trying to convince owners to do more. However, when low initial cost is required by owners, suboptimal zoning choices, such as grouping even more offices together, are common. Owners need to be made aware that such frugal zoning will result in more hours per year of discomfort in the rooms without thermostats.

Design Principles

The following HVAC-design guidance assumes that all spaces under consideration are to be conditioned toward similar thermal comfort and ventilation goals. Buildings, uses, and codes vary, so these guides may need adjustment:

FIGURE 1 Thermal zoning will vary depending on the exposure to the outdoors through the roof, walls, and sub-grade walls and floors. ©Rock Consulting Engineers, used with permission



1) *Zones are composed of spaces that are arranged horizontally within a commercial building, and not vertically*. This is because floors between spaces are fire and smoke barriers, thus openings or uncontrolled air movement between stories defeat basic fire protection compartmentation principles. It also recognizes that loads do vary floor-to-floor, as shown in *Figure 1*, and that there may be different tenants by floor. Exceptions to this rule include stair towers and atria. Also, in U.S. residences thermal zones do frequently extend over two or more levels, often resulting in poor comfort on the floors without the thermostats, or over-conditioning on the floors with them.

2) *Zones are assembled from adjacent spaces.* While two spaces that are distant may have similar load profiles, they may be so far apart that it is not practical to connect them with zone-level ductwork or piping. Instead, such distant spaces are connected to others nearby, or are defined as separate zones.

3) *Interior spaces are linked with other interior spaces.* Having little or no thermal communication with the exterior, except via ventilation air and possibly the roof, usually makes grouping interior spaces together easier than with exterior spaces. Complications arise when skylights are present, or spaces have significantly different uses, setpoints, or ventilation needs. However, in smaller low- and sometimes medium-cost commercial buildings, all

the spaces in the core are often grouped together into one thermal zone, even if storage rooms and other low-use spaces are over-conditioned.

4) *Exterior spaces are linked with some other exterior spaces of the same solar exposure.* And perimeter spaces are never to be linked with occupied interior spaces. Designers will often put no more than three single-person perimeter offices on one zone, but will increase this to five or possibly more offices when budgets are too tight.

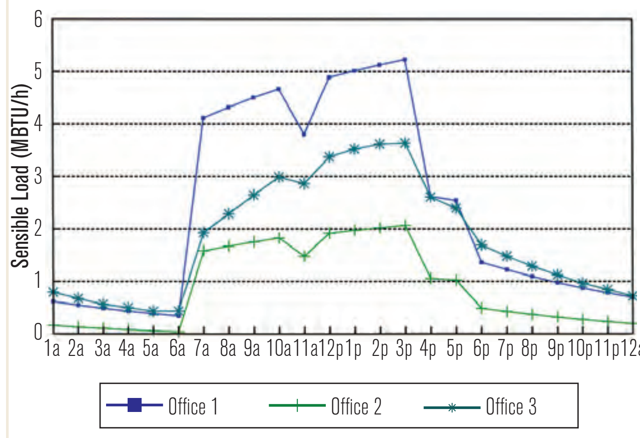
5) *If the construction and operation finances allow, transiently occupied spaces can be designated as separate thermal zones for improved comfort in them.* For example, typically in high-cost buildings, their hallways, restrooms, and storage rooms, for example, can be made separate zones to give them superior comfort. Hotels' vending/ice-making rooms for guests, with their high equipment heat gains, are an example need for separate zoning and conditioning. However, in most buildings some or all of these spaces are typically just linked to neighboring spaces that have regular, higher-priority occupancy and some or many hours of discomfort can be expected in those support spaces. In the distant past, many interior spaces such as hallways and storage rooms had little or no conditioning or ventilation because then-conventional wisdom decreed that these spaces were rarely used, and were ventilated sufficiently by transfer air.

6) *Thermal zones do not usually appear directly on finished drawings.* Readers of such bid, construction, or as-built drawings must infer the thermal zones by tracing the outlines of ducting or piping systems from each terminal unit, pump, or control device, for example. HVAC drawings can be very "busy" and thus difficult to read, so do consider including separate thermal zoning diagrams, even if shown at a much smaller scale, to be helpful to others on complicated projects.

Automatic Zoning

In 2001 the author did an unpublished study on whether then-current modeling software could be used to "autozone" spaces of a building. A small, one story, masonry, under-insulated office building was used, and all its rooms included in DOE 2.1E[11] as separate thermal zones. *Figure 2* shows the resulting hour-by-hour sensible cooling loads on June 21st for three of the offices; the entire building and year were modeled, however. Offices 1 and 2 are internal spaces, but of differing floor areas. Office 3 is a perimeter space, and also of different

FIGURE 2 The sensible heating loads on June 21 for three office spaces in one small, poorly insulated building. Office spaces one and two likely can be zoned together, but the profile of office space three is too different.



floor area. Despite having similar internal loads per unit floor area, none of the sensible loads are equal for this day. However, for zoning decisions, the magnitudes of the loads are not important, but instead the load profiles must be similar so that the air or water flow rates, of fixed proportion of the zone's total, will keep each space comfortable under various conditions.

For the single day shown in *Figure 2*, the cooling load profiles for Interior Offices 1 and 2 are very similar and suggest that they should be zoned together, at least based on this traditional design-day. However Office 3, which is exposed to the exterior via a high mass, low R-value masonry wall, has a significantly different sensible heat load profile for that day. This suggests that Office 3 should not be zoned with 1 or 2. Later, published studies have created autozoning algorithms, with a mass, construction, orientation, and perimeter- vs. core-weighted version now included in at least one commercial product's algorithms, as an option. So far, these autozoners are intended for the typically simpler zones used for energy modeling and not necessarily those for HVAC design.[12,13]

Special Challenges

Corner Offices

With solar-exposures on two or more sides, corner and penthouse offices present design challenges, thermal as well as social. Occupants of these spaces are usually higher-ranked members of their organizations and their comfort expectations often exceed that of others. Making these spaces separate thermal zones, with their own thermostats, is best. If they must be linked with neighboring single-exposure offices the corner rooms still get the T-stats; the other spaces' occupants may suffer at times especially when the different exposure of the corner office is in sunlight. In the northern hemisphere, the southwestern corner offices tend to be the most problematic due to high late-afternoon air temperatures outdoors, and low angle, from-the-west sunshine.

Hallways

In typical light commercial buildings, of low to moderate cost, hallways are often subdivided and attached to the nearest, often exterior rooms. Because hallways are normally interior spaces, this can lead to their over-conditioning and ventilating, and possibly too much variation in temperature as someone walks a long hallway, passing zone to zone. Making hallways their own zones improves comfort and potentially smoke management, but budgets rarely allow this for low and moderate cost projects. Attaching restrooms, storage, or other core support spaces to the hallway zone is often a good solution, with the thermostat placed in the region of most-frequent occupancy. Because thermostats protrude from walls, when locating them in hallways watch for circulation patterns that could interfere.

Conference Rooms

Many of these spaces go unused for hours or days, but then are suddenly filled, or overfilled, with occupants. Common complaints, typical for when zoned with other spaces, are that conference rooms without thermostats are too cold upon entry, then hot, humid, and stinky by the latter part of a big meeting. When possible, such rooms should be zoned separately and have rapidly responding controls and systems.

Retrofitted Computer Labs

For new buildings, spaces with very high internal heat gains such as from computing equipment can be zoned and designed for appropriately. However, a change of use of an existing space, e.g., from general-use to a high density computer lab, often generates complaints. Making the room a separate thermal zone may be needed. However, owners often neglect to have their HVAC systems evaluated for appropriate zoning and enough cooling-capacity, or, worse, choose not to make needed modifications due to cost. Hot, stinky rooms and sticky keyboards result.

Large, Open Spaces

One huge space can, and often should be divided into separate zones. A wide perimeter room may, at times, need heating at its exterior while simultaneously requiring cooling the interior of its floor area. "Big box" stores and conditioned warehouses are usually served by multiple smaller rooftop units, rather than one large unit, so defining at least one zone per RTU is logical; their thermostats are typically mounted on columns below, often with perforated guards around them. Theaters and enclosed arenas can benefit by defining one or more zones for the entertainers or athletes, another for small, close-in crowds, and one or more zones for large crowds farther away.

High-Use Entrances and Loading Docks

These spaces, typically on ground-level, open to the exterior and can have huge in-rushes of unconditioned outdoor air. Vestibules, rotating doors, and active air pressure management can reduce this infiltration, but at times, such as the beginning of the workday or when unloading a truck, this infiltration frequently overwhelms an HVAC zone. If other spaces are connected, discomfort can occur in them too due to over-conditioning. Consider not only making entrances separate zones, but also subdividing or taking other measures so that, for example, a receptionist doesn't have to suffer on cold winter mornings.

Restrooms and Janitor Closets

These spaces, as well as others that have high internal pollutant generation rates such as indoor smoking rooms, paint booths, and welding areas, can have none of their air recirculated, but instead all must be exhausted outdoors. These spaces can, however, be zoned with others for supply air purposes. Using some or all transfer air for them, instead of all supply air, may be more appropriate, though.

Unconditioned Spaces

In addition to the occupied spaces, unconditioned spaces such as attics, crawlspaces, ceiling and floor plena, attached garages and sheds, large chases, and elevator shafts may need zoning too. With the advent of transient thermal analyses, e.g., with the transfer function and now the heat balance calculation methods, it is best to include unconditioned spaces in the overall

FIGURE 3 An intermediate-level of a lower-cost multistory office building. The core is a single thermal zone, while the entire perimeter of offices is divided into only five zones. Occupants of the non-corner offices will be uncomfortable at times because the two-exposure corner offices will get the thermostats. ©Rock Consulting Engineers, used with permission

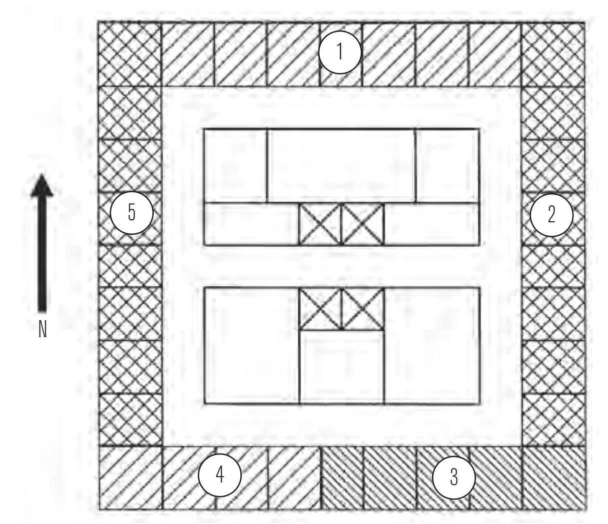
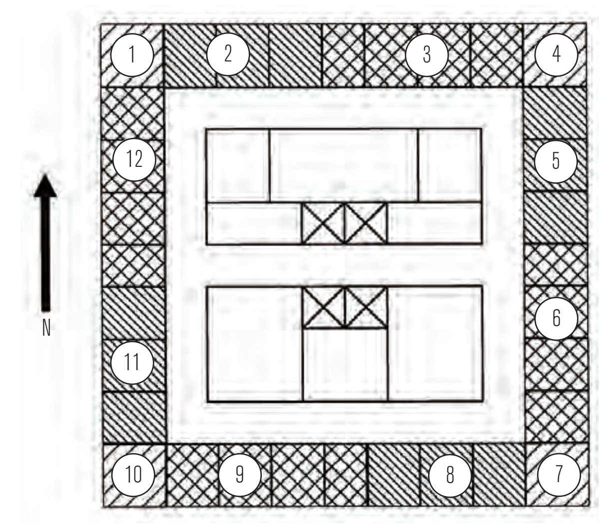


FIGURE 4 The same intermediate floor as shown in *Figure 3*, but with a larger HVAC budget so more perimeter and possibly more core zones can be defined. With each two-exposure corner office having its own zone and thermostat, the single-exposure offices should have few hours of discomfort by being in their own zones. ©Rock Consulting Engineers, used with permission



simulation. These spaces' temperatures, humidities, and air qualities will float via their communication with their neighboring conditioned spaces, and with the outdoors. Traditionally, an overhead plenum in an office space was included with the occupied room below it, for example. However, ceilings can have significant thermal resistances, and plena or attics just below roofs can have very high heat losses and gains. They may have high mass elements and equipment too, so they are, at times, much warmer or cooler than the occupied spaces below, especially if a roof above one has a low thermal resistance or its exterior is dark in color.

Classical Example

Figure 3 shows a classical zoning design problem being the intermediate floor of a high-rise office building in the Northern Hemisphere; *Figure 3* is for low-cost and *Figure 4* is for a moderate or higher cost design. The exterior curtain-walls have much glass, so solar heat gains are extremely high depending on the time of day and year, weather, and exposure. Heat losses from the windows during cold weather are substantial as well. This building's offices are placed around the perimeter of each floor. The core of a building such as this may have office spaces as well, but there are usually mail, copier, break, conference, storage, building services, and IT rooms, as well as janitorial spaces, restrooms, and corridors in them. Elevators and stair towers are frequently in the core. Because of the lack of solar gains, many of the core's spaces are typically zoned together. However, if the spaces are for different tenants, they should be separated.

Because of the heat gains through the enclosure, the perimeter typically requires more careful zoning than the core. In the example shown in Figures 3 and 4, the solar gains through the large windows, as well as the desired low construction cost, will likely dominate the perimeter zoning decisions. Under heat loss "worst-case" design conditions—night, cold, and windy— all of the offices would have similar patterns of heat losses, except that infiltration will vary depending on several factors. However, when solar energy is available the perimeter spaces behave significantly different from each other depending on exposure. On a cold, clear winter morning, for example, the east-facing offices may not need much heat, if any, due to solar heat gains. At the same time the westerly offices may need significant heating. In the afternoon, as the outdoor air warms and the building's thermal masses are "charged," the western offices will likely need substantial cooling while the eastern offices need a much lower rate of cooling, or even some heating on very cold days.

The southern offices—or northern in the Southern Hemisphere—should have their peak cooling loads in the early- to mid-afternoon, and won't peak with either the east or west spaces. If the building is in the temperate or colder regions of the Northern Hemisphere, the north-facing offices won't receive any direct sunlight in the winter, so their loads are different from spaces in the other exposures. From a purely solar energy point-of-view, each exposure should at least be zoned separately. The higher-cost zoning shown in *Figure 4*, and with appropriate systems installed, should yield improved occupant satisfaction and fewer occupant-conflicts over their thermostats.

Conclusions

In manual and computer-based transient load calculations, HVAC designers usually must select the thermal zones before the detailed loads are known. In selecting which rooms to group together to form a zone the magnitude of the rooms' heat gains and losses should not be a factor, but instead the profile of those gains is more important—the air or water flow to the zone is easily divided to meet each room's needs. Fortunately, from one point-of-view, certain software packages have added autozoning capabilities at least for energy estimating, and these algorithms will increase in complexity through time.

The "Nonresidential Cooling and Heating Load Calculations" chapter of the *2017 ASHRAE Handbook* says "… zones[,] as defined for load calculations and air-handling units[,] ha[ve] no effect on room cooling loads."[14] This author must respectfully disagree; as discussed here, a particular room without the zone's thermostat may have significantly different temperatures, humidities, or ventilation rates, and thus loads, at times as compared to it having optimal indoor conditions. The chapter does state that zone-selection may affect peak loads for system sizing, and that one system with many zones may have lower overall capacity than for the same building with many small single-zone systems because of zones peaking at different times. Having software iterate to determine not only the comfort but also the energy effects of various zoning choices would be a powerful tool for HVAC designers.

So is thermal zoning an art, or is it a science? Like good home cooking, it is both. A well-informed, experienced HVAC designer will study each space's intended use and occupancy, window and wall areas, construction, cardinal orientation and area of exposure to the outdoor, and its ventilation needs before making zoning decisions; if automated zoning is used in software, the designer must use the same knowledge, skills, and experience to evaluate its suggestions. After construction, designers' on-site observations, and the feedback from owners, operators, and occupants, can help improve future zoning decision-making and increase building performance.

Acknowledgments

This work was supported by Rock Consulting Engineers and the University of Kansas, both of or near Lawrence, Kan.

References

1. O'Brien, W., A. Athienitis, T. Kesik. 2011. "Thermal zoning and interzonal airflow in the design and simulation of solar houses: a sensitivity analysis," *Journal of Building Performance Simulation*,4(3):239–256, Taylor and Francis, London.

2. Smith, L. 2012. "Beyond the shoebox: thermal zoning approaches for complex building shapes," *ASHRAE Transactions*,118(2):141–148, ASHRAE, Inc., Atlanta, Ga.

3. Rose, R., J. Dozier. 1997. "EPA program impacts office zoning," *ASHRAE Journal*, 39(1), ASHRAE, Inc.

4. ASHRAE. 2018. ASHRAE Terminology. www.ashrae.org/technical-resources/free-resources/ashrae-terminology, ASHRAE, Inc.

5. ASHRAE. 1991. *ASHRAE Terminology of Heating, Ventilation, Air-Conditioning, and Refrigeration*, ASHRAE, Inc.

6. Rudoy, W., J. Cuba. 1979. *Cooling and Heating Load Calculation Manual*, ASHRAE, Inc. Also the four later ASHRAE "load calculation manuals" by F. McQuistion and J. Spitler, 1992; Pedersen et al., 1998; J. Spitler, 2009; and J. Spitler, 2011.

7. McFarlan, A. 2010, reprinted from 1959. "Improved zoning betters department store air conditioning." *ASHRAE Journal*, 52(2):42–48, ASHRAE, Inc.

8. Rock, B.A., C.A. Hillman. Sept. 1996. "Post-occupancy indoor environmental quality evaluation of an institutional building," *ASCE Journal of Architectural Engineering*, 2(3):88–94, ASCE, Reston, VA.

9. ASHRAE. 2017. 2017 Fundamentals volume of the *ASHRAE Handbook*, p. 19.14-15, ASHRAE, Inc.

10. Merriam-Webster. 2018. Online Dictionary. www.merriam-webster.com/dictionary/dictionary, Merriam-Webster, Inc., Springfield, Mass.

11. U.S. DOE. 2001. *DOE-2.1E Energy Analysis Software*, Lawrence Berkeley (National) Laboratory, Berkeley, Calif.

12. T. Dogan, P. Michelatos, and C. Reinhart. 2015. "Autozoner: An algorithm for automatic thermal zoning of buildings with unknown interior space definitions," *Journal of Building Performance Simulation*, vol. 9, no. 2, pp. 1-14, Taylor and Francis, London.

13. Autodesk. 2018. *Revit®* building information modeling software, Autodesk, Inc., San Rafael, Calif.

14. ASHRAE. 2017. *ASHRAE Handbook—Fundamentals,* p. 18.41, ASHRAE, Inc. ■