# Technical Article



# Too Hot | Too Cold

## Diagnosing Occupant Complaints

**By Glenn Friedman, P.E.,** Member ASHRAE

**When an HVAC system works, building occupants don't even know it's there—no news is good news. The bad news is, in a recent survey done by the International Facility Management Association,[1] too cold and too hot ranked first and second of top 10 office complaints.**

Hot and cold problems can be caused by many factors: too little capacity, too much capacity, lack of zoning, too little control, varying space usage, varying solar load, changes in occupancy, changes to the space envelope, drafts and diffuser performance, or too little ventilation.

The following is a guide for engineers, contractors, building managers and owners confronted with hot/cold problems. The article covers the basics of hot/cold complaint diagnosis and then describes additional technical steps for diagnosing complaints.

### Complaints

Complaints usually come from building occupants who may not be able to distinguish between drafts and being too cold or between stuffiness and being too hot. If you hear, "The room is stuffy," the true problem could be temperature, solar load, radiant heat from windows and walls or lack of ventilation.

Start the hot/cold complaint review by evaluating an occupant's complaint. Then review the HVAC equipment performance for proper operation followed by a system design analysis.

It is worth validating the hot/cold complaint to evaluate whether the complaint is an HVAC issues or a management issues. Chapter 8, Page 8.17 of the *2001 ASHRAE Handbook—Fundamentals* points out that, for typical comfort conditions, 5% of the people will be dissatisfied. Research reported in *ASHRAE Transactions* finds that even with perfect temperature control complaints occur.[2] If individual occupant control is not justified, do not expect every occupant to be satisfied with the same conditions.

**About the Author**

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**Validation**

Start by getting a detailed explanation of the hot/cold complaint. Then, visit the space. Observe and measure the conditions using the Validation section of the checklist. The following tests reference common industry practice design parameters. If specific building guidelines are available, they should supersede the industry common practice design parameters.

If all answers to the seven Validation questions are "no," the complaint is a management issue rather than an HVAC system issue per normal building guideline performance expectations.

If the answer to Questions 1, 2, 3, or 4 is "yes," proceed to Load Calculations.

If the answer to Question 5 is "yes," remedy the situation with internal or external shading. If the occupant wishes to experience direct sunlight, then explain that normal comfort space temperatures will not satisfy an occupant in direct sunlight.

If the surfaces are hotter or colder than the space temperature, they can produce a radiant effect for nearby occupants. If the answer to Question 6 is "yes" and the radiant temperature of surfaces is the cause of the hot/cold complaint, reduce the radiant effect. Options may include moving the occupant further from the radiating surface, installing shades or curtains on glazing, retrofitting windows with thermally insulated glazing, adding insulation and furring the walls.

If the answer to Question 7 is "yes," this is not a true hot/cold complaint. Address the lack of outside air ventilation by adjusting the outdoor air ventilation control.

**HVAC Equipment Operation Review**

Operate the HVAC systems through their sequences that relate to the hot/cold complaint; measure the system performance including fan operation, heating and cooling cycles and compare the readings to the design system specifications and the equipment manufacturers' specifications. This work is potentially dangerous and is best performed by skilled technicians experienced in the testing and commissioning of HVAC systems. Any equipment or system operation that does not perform to design specification or manufacturer's operating specifications should be analyzed and repaired.

If the system is equipped with a building automation system, trend logs can be recorded to gather much of the system performance. Trend logs should be reviewed for proper operation and performance anomalies. Anomalies should be analyzed and corrected.

**Load Calculations**

Load calculations are usually the next item checked after verifying the equipment is working properly. Load calculations model the building envelope and internal heat gains to size HVAC equipment and distribution systems. Block loads are load calculations for an entire building or major equipment area. Space loads are load calculations for individual spaces.

The Load Calculations section of the checklist compares the load to the installed equipment capacity. If the answer to either Block Load Question 1 or 2 is "no," the building requires additional capacity.

If the answer to either Space Load Question 1 or 2 is "no," the space requires more capacity.

After the capacity issues are addressed, this is often the point when the basic hot/cold complaint evaluation concludes and many hot/cold complaints are not resolved. However, there is more to hot/cold complaints than insufficient capacity. Now let's investigate zoning, control, drafts and humidity.

**Zoning**

The *ASHRAE Terminology of Heating, Ventilating, Air Conditioning, and Refrigeration,* defines zoning as:

## Campfire Radiation

Did you ever sit by a campfire and notice how comfortable you were even though the temperatures were hot on your clothing facing the fire and cold on your clothing away from the fire? At this same time the outside air temperature might have been 50°F (10°C) or colder. The temperature you perceived was radically different than the actual air temperature.

The body's perceived temperature is dramatically affected by direct radiation such as a campfire. The same radiation affect holds true sitting in direct sunlight, such as in a car. Car air conditioning allows the occupants to vary temperatures and create drafts for occupant comfort. Standard building design is for a steady temperature and draft free environment. For building comfort, *keep sunlight off occupants*.

## Stratification Research

Researchers are studying the effects of stratification on human comfort. Though the 2°F (1.1°C) floor to desktop test for stratification in the occupied zone for a conventional commercial space with ceiling supply diffusers is achievable for a well designed space, this low level of stratification is not required for comfort. However, when the stratification is greater than this, it is likely the diffusers are "dumping," or not mixing properly at the ceiling. For underfloor air distribution stratification of 5.4°F (3°C) within the lower 6 ft (1.8 m) of a space is not uncommon and considered comfortable. Therefore, it would be hard to condemn a quality installation simply because there is stratification. Since there is ongoing research in this area and little documentation to reference, this guide is purposefully vague about stratification.

# Diagnosing Hot/Cold Complaints Checklist

## Validation

| | Yes | No |
|---|---|---|
| 1. Is there any part of the occupied zone* outside the ASHRAE comfort range during normal building operating hours? (*The occupied zone refers to the occupied building area from the floor to 6 ft above the floor.) | | |
| 2. Using a sensitive and fast-response recording thermometer does the occupied zone temperature fluctuate more than 5°F in less than 10 minutes during the occupied period? | | |
| 3. At the complaint location is there stratification between 4 in. above the floor and desk top height, that exceeds 2°F[3] for well-mixed spaces or between 4 in. above the floor and 6 ft that exceeds 5.4°F[4]* for underfloor air supply or displacement ventilation spaces? (*This is for a Class B space. For other ratings see ANSI/ASHRAE Standard 55-1992/55-2000R, public review draft, *Thermal Environmental Conditions for Human Occupancy*.) | | |
| 4. Are there any noticeable continuous drafts in the occupancy zones? | | |
| 5 Is there ever direct sunlight on the occupants? | | |
| 6. Are the windows or any wall or building surfaces unusually hot or cold to the touch? | | |
| 7. Does the $CO_2$ level in the occupied zone ever exceed 700 ppm above the outdoor air levels[5] for more than a 15-minute period? (This item does not directly relate to a hot/cold complaint; however, evaluating a "stuffy" complaint involves distinguishing between a "too hot" problem and a ventilation problem.) | | |

**Actions:** If all the answers to Questions 1–7 are "no," the complaint is a management issue rather than an HVAC system issue. If the answer to Questions 1, 2, 3 or 4 is "yes," proceed to Load Calculations. If the answer to Question 5 is "yes," remedy the situation with internal or external shading.

**Equipment Functional Review:** Operate the HVAC systems through their sequences that relate to the complaint; measure system performance including fan operation, heating and cooling cycles and compare the readings to the design system specifications and the equipment manufacturers' specifications. This work is potentially dangerous and is best performed by skilled technicians experienced in the testing and commissioning of HVAC systems. Any equipment or system operation that does not perform to design specification or manufacturer's operating specifications should be analyzed and repaired.

## Load Calculation

| Block Load | Yes | No |
|---|---|---|
| 1. Is there enough heating capacity to handle the block-heating load including capacity for distribution losses and morning warm-up/recovery? (Allowances of 10% to 20% of the net calculated heating load for distribution losses to unheated spaces and 10% to 20% more for a warm-up load are common practice.)[6] | | |
| 2. Is there enough cooling capacity to handle the block-cooling load? | | |

**Actions:** If the answer to either Block Load Question 1 or 2 is "no," the building requires additional capacity.

| Space Load | Yes | No |
|---|---|---|
| 1. Is there enough heating capacity to handle the space-heating load including capacity for morning warm-up/recovery? | | |
| 2. Is there enough cooling capacity to handle the space-cooling load? | | |

**Actions:** If the answer to either Space Load Question 1 or 2 is "no," the space requires more capacity.

## Zoning Conflicts (Simple)

| | Yes | No |
|---|---|---|
| 1. Are any of the spaces in the zone on a different floor level? | | |
| 2. Do any of the spaces in the zone have different ceiling heights? | | |
| 3. Do any of the spaces in the zone have different outdoor exposures than other parts of the zone? | | |
| 4. Do any of the spaces in the zone have intermittent internal gains such as a conference room or a lunchroom? | | |

**Actions:** If the answer to any of the Zoning Conflicts (Simple) questions is "yes," consider additional zoning.

**Control Review:** Verify the space temperature does not vary more than 5°F in less than 10 minutes. Raise the space temperature setpoint by 4°F and review response. After the space has stabilized at the new setpoint, reset the space temperature setpoint back to the original setting and review response. If the space temperature does not control properly, revise the controls design, which may require revising the system type.

## Draft Problems

| | Yes | No |
|---|---|---|
| 1. Are the grille patterns adjusted properly for the application? For example, are the linear slot diffusers adjusted for horizontal airflow? Are there any return grilles with no directional blades being used for supply air? | | |
| 2. Are any of the supply grilles blowing air towards an adjacent wall or window creating noticeable drafts? | | |
| 3. Are there any obstructions in the distribution air path that would allow primary air to contact the occupants before getting well-mixed? | | |
| 4. Is there any dumping (primary air cascading down into the occupied zone) while standing near the problem area's ceiling supply diffusers with the system on cooling and the zone on minimum airflow? | | |

**Actions:** If any of the draft problem answers is "yes," resolve the problems using ADPI criteria.

**Humidity Review:** Use a wet bulb thermometer and confirm the humidity ratio does not exceed 84 grains of moisture or 0.012 lbs of moisture per pound of dry air during a complaint period. If this level is exceeded, calculate the dehumidification load for the wet-bulb design condition. If the system has enough capacity for the cooling and dehumidification load, add humidity control. If not enough capacity exists, design a new system to supplement the existing HVAC system or replace the existing HVAC system.

## Zoning Conflicts (Advanced)

| | Yes | No |
|---|---|---|
| 1. Do the individual space proportional cooling airflows at monthly peak loads vary more than 10%–15% throughout the year? | | |
| 2. Do the individual space proportional heating airflows at monthly peak loads, including the internal gains, vary more than 10%–15% throughout the year? | | |
| 3. Do the individual space design proportional heating airflows including the internal gains differ from the space design proportional cooling airflows by more than 10%–15%? | | |

**Actions:** If the answer any of the questions in Zoning Conflicts (Advanced) is "yes," additional zoning is required.

**Draft Review (Advanced):** If airflow testing is available, the measured velocity in the occupied area in all directions should be equal to or less than 30 fpm for heating and 50 fpm for cooling. If these conditions are not met, resolve the draft problems by modifying the grilles using ADPI criteria.

***Zoning***

> *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.*

To properly zone spaces, the second definition must hold true "…*that one thermostat can be used to determine its requirements.*" If one thermostat does not accurately represent all the areas of the zone, expect hot/cold complaints.

Traditionally, zoning is done by experienced engineers as an art, not a science. It would be wonderful if load calculations provided the science of evaluating whether space temperatures would deviate from the thermostat space temperature within a given zone. Unfortunately, as stated in the *2001 ASHRAE Handbook—Fundamentals,* Chapter 29, most load calculation procedures make assumptions such as:

> *"The most fundamental assumption is that the air in the thermal zone can be modeled as well mixed, meaning it has a uniform temperature throughout the zone."*

Thus, zoning requirements are not calculated by normal load calculation procedures. However, we can use conventional load techniques to evaluate some zoning problems. For zones to work with single-point thermostatic control, the proportional capacity requirement must not change significantly for a variety of internal and external load variations. This approach is discussed in a subsequent section of this guide.

Rather than doing a significantly more complex analysis, investigate the zoning conflicts using the Zoning Conflicts (Simple) section of the checklist.

If the answer to any of the questions in the Zoning Conflicts (Simple) section is "yes," consider additional zoning.

**Control**

Building controls are intended to maintain steady space temperatures. Control loops that respond too fast or too slow can result in hot/cold complaints. A control loop response time is too fast when it responds faster than the control sensor responds. A control loop is too slow when it responds slower than the control sensor responds.

If the control loop response is too fast, the space temperature can overcorrect and result in wide temperature fluctuations. This situation is worst when there is excess capacity. Two examples of this include oversized packaged units without modulating control and variable-volume, variable-temperature, changeover systems with oversized space ducts.

The first example, oversized packaged units without modulating control, deals with variations in load by cycling heating or cooling stages. If the staged capacity of the packaged equipment serving a space is oversized for the demand and the control loop response time is too fast, the space will cycle stages of heating or cooling and condition the space faster than the control sensor can provide feedback resulting in over conditioning. The zone will cycle from heating to cooling to compensate resulting in hot/cold complaints.

The second example, variable-volume, variable-temperature, changeover systems, typically uses packaged equipment to provide heating and cooling to multiple zones by both modulating dampers and changing from heating to cooling to satisfy multiple simultaneous demands. In a variable-volume, variable-temperature, changeover system with oversized space ducts, when there is a minor demand for cooling in one zone while the other zones are satisfied or in heating, at some point the system will change over to a demand for cooling. This demand for cooling will close all the other zone dampers but the single zone damper demanding cooling, which results in significant cold airflow to

## Cost Of Complaints

The savings of not zoning is far exceeded by the cost of retrofitting additional zones. But the cost of retrofitting can be further eclipsed by the cost of lost opportunity for a project once it is labeled an HVAC deficient building.

We received a hot/cold complaint from a housing development. Not only was the developer having trouble selling its homes, but also the owners of some of the homes that had been sold were threatening legal action. Our investigation showed the developer had saved money on their smaller two-story homes by installing a single central HVAC system. The solution involved retrofitting a costly variable volume variable temperature changeover system to create separate zones for each level in the homes.

## Gambling With Comfort

Shortly after it opened we analyzed the main gambling room of a casino for hot/cold complaints. The room was served by a single zone constant volume unit with 60% outside air. The airflow was high, more than 7 cfm/ft$^2$ (35.6 L/s per m$^2$). On cold days the supply temperature would vary from 50°F (10°C) during the no-heating call to a supply air temperature of 85°F (29°C) on a call for heating. We watched as occupants put their jackets on or take their jackets off every time the heating cycled off or on, respectively. Though the occupants were too intent on gambling to complain, we saw there was a problem. We found that at 7 cfm/ft$^2$ (35.6 L/s per m$^2$) airflow the air temperature changed more quickly than the space temperature sensors could react. To fix this we changed the control to a cascading loop that controlled supply air temperature reset from the room sensor. This control gradually changed the supply air temperature at a rate that the space temperature sensors could react to and solved the problem.

the zone demanding cooling. The zone temperature cools more rapidly than the zone temperature sensor and the space overcools. The analogous problem can happen in the heating cycle.

If the control loop response is too slow, the space temperature does not respond to changes in the load. For example, if the sun goes behind a cloud reducing the solar heat load the slow control loop response time causes the zone to overcool before responding.

Confirming temperature fluctuations may require more frequent and sensitive monitoring than typical trend logs using the direct digital control (DDC) system room sensors. If the DDC system room sensors are responding too fast or too slow, a trend log may not indicate the temperature fluctuations felt by the occupants. Also a long trend log interval may be long enough to effectively *even out* the temperature fluctuations. A five-minute trend log interval may appear fine, even though people in the space may have hot/cold complaints.

A good tool for checking temperature fluctuation is a fast acting and sensitive data logger to log the space temperature at one-minute intervals or less. Verify that the space temperature at the location of the hot/cold complaints does not vary more than 5°F (2.8°C) in less than 10 minutes. Raise the space temperature setpoint by 4°F (2.2°C) and review the response. Are there unusual fluctuations in temperature? After the space has stabilized at the new setpoint, reset the space temperature setpoint back to the original setting and review the response. If the space temperature response is too slow, the space temperature may not recover fast enough.

If the space temperature does not control properly, revise the controls design, which may require revising the system type.

## Alternatives to Reduce Hot/Cold Complaints

ANSI/ASHRAE Standard 55-1992/55-2000R, public review draft, *Thermal Environmental Conditions for Human Occupancy,* states that building occupants like direct control over their environment. Under the same environmental conditions when people have direct control, more people are satisfied. Building owners are finding positive results from providing building occupants individual direct control features such as access to thermostats, operable windows and underfloor air distribution with adjustable grilles.

### Drafts

Drafts can be the result of poor system performance or grille selection. The initial observation walk through can reveal many of the potential problems without requiring detailed measurements or expensive tests.

Primary air is the air coming from the supply duct. The primary air is mixed with the room air as it is introduced to the space through the supply grille. Occupants should not be subject to contact with primary air before it is well mixed.

Examine the grilles and observe their direction airflow pattern based on the grille configuration. See if you experience drafts. Use the Draft Problems section of the checklist.

If any of the draft problem answers in the Draft Problems section is "yes," resolve the problems using ADPI criteria (see the Technical Draft Analysis section later).

If diffusers are not throwing air far enough (with enough velocity), which can happen at part load in VAV systems, cold air may drop to the floor without mixing. The result is excessive table top to floor stratification. A side effect of this is that thermostat response can be extremely slow since the space is not well mixed. Selecting diffusers that have longer throw will often change the thermostat response significantly, resulting in better response to changing loads and system fluctuations.

When heating from the ceiling, the *ASHRAE Handbook—Fundamentals,* Chapter 32, recommends that the primary air temperature not be more than 15°F (8.3°C) above room temperature to avoid stratification and ventilation short-circuiting. BSR/ASHRAE Addendum *n* to ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality* (formerly Addendum *n* to ANSI/ASHRAE Standard 62-1999), now requires an increase in ventilation rates if discharge temperatures exceed 15°F (8.3°C) above room temperatures.

Continuous drafts usually result from the supply jet of a diffuser projecting into the occupied space. Change the diffuser locations, settings or selections to correct these situations.

### Humidity

The upcoming revision to ANSI/ASHRAE Standard 55-1992/55-2000R, Public Review Draft, *Thermal Environmental Conditions for Human Occupancy*, defines an upper humidity ratio of 0.012. This is 65% RH at 75°F (24°C) or a 62.2°F (16.8°C) dew point. There is no lower limit humidity level defined in the updated standard. Measure the humidity level using a wet bulb thermometer and confirm the humidity ratio does not exceed 84 grains of moisture or 0.012 lbs of moisture per pound (12 g/kg) of dry air during a complaint period. If this level is exceeded, calculate the dehumidification load for the wet-bulb design condition. Do not use the mean coincident wet-bulb design condition to calculate the humidity load. If the existing system has enough capacity for the cooling and dehumidification load, resolve the humidity problem by adding humidity control to the existing HVAC system. If necessary include reheat as part of the humidity control. If there is not enough capacity in the existing HVAC system, design a new system to supplement the existing HVAC system or replace the existing HVAC system.

### Technical Zoning Analysis

Design conditions are for design heating and cooling days. These conditions are normal peak weather and normal peak operating conditions. Run the load calculations for a variety

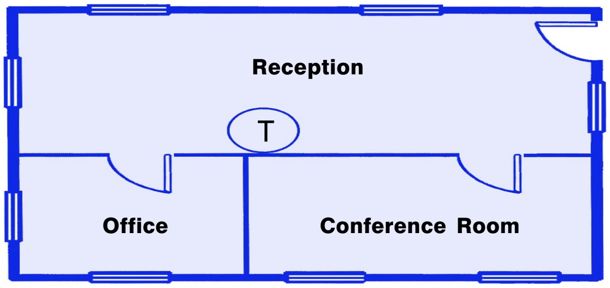


*Figure 1: Simple example building for zoning analysis.*

| Space | September | | April | | February | |
|---|---|---|---|---|---|---|
| | 83°F Design Temp. | | 74°F Design Temp. | | 65°F Design Temp. | |
| | Airflow, cfm | Percent Of Total Airflow | Airflow, cfm | Percent Of Total Airflow | Airflow, cfm | Percent Of Total Airflow |
| Reception | 499 | 44 | 415 | 43 | 519 | 63 |
| Office | 284 | 25 | 243 | 25 | 136 | 17 |
| Conference | 352 | 31 | 312 | 32 | 165 | 20 |
| Total | 1,135 | 100 | 970 | 100 | 820 | 100 |

*Table 1: Cooling airflow requirements per space for Figure 1.*

of annual design conditions and see if the proportional capacity requirements between different spaces in the zone stay fairly constant. Let's look at the simple example in *Figure 1*. The example building is a single-story, stand-alone, three-room office building with single pane glazing. *Table 1* is the cooling airflow requirements per space at different months' outdoor design temperatures.

If the airflow is designed at the peak load conditions for September, the system would be reasonably conditioned in April. However, in February the office and the conference spaces would be overconditioned. This indicates that this is not appropriate zoning; more zoning is required.

Most buildings do not warrant the thoroughness of an exponentially more complicated building simulation to analyze all the different conditions during the year such as sunny days and rainy days, summer and winter conditions, and varying internal loads like conference rooms with and without people and lights. However, for a useful and more rigorous zoning analysis than the Zoning Conflicts (Simple), run monthly load calculations for the Zoning Conflicts (Advanced) as described in *Table 1*.

If the answer any of the questions in Zoning Conflicts (Advanced) section is "yes," additional zoning is required.

### Technical Draft Analysis

The following discussion of drafts is more involved and technical than most hot/cold complaint investigations require. Observation, standing in the space, feeling for drafts and simple temperature measurements at the floor, tabletop and 6 ft (1.8 m) above the floor will provide most of the useful diagnostic information.

The *2001 ASHRAE Handbook—Fundamentals,* Chapter 32, describes the Air Diffusion Performance Index (ADPI) for cooling conditions. ADPI takes into account the cooling effect of air temperature and air motion on comfort. ADPI can be calculated using the procedures in *Fundamentals*.

*Fundamentals* states a comfort criterion using the ADPI effective draft temperature equation:

> *"A high percentage of people are comfortable in sedentary (office) occupations where the effective draft temperature θ …is between –3 and +2°F and the air velocity is less than 70 fpm."*

θ is defined as:

$$\theta = (t_x - t_c) - 0.07(V\,x - 30)$$

*where*

θ = effective draft temperature, °F
$t_x$ = local airstream dry-bulb temperature, °F
$t_c$ = average (control) room dry-bulb temperature, °F
$V_x$ = local airstream centerline velocity, fpm

ADPI is the comfort criteria expressed as a percentage. Thus, an occupied space with an ADPI rating of 80 translates to a prediction that 80% of the occupants are satisfied in the occupied space. More importantly, when the ADPI is 80% or higher, effective mixing in the space is assured and stratification is unlikely.

Since the procedures above are technical, and generally not performed, a practical approach is to determine ADPI from grille manufacturers' data. For each occupant location, use the grille manufacturers' data to determine the ADPI at 6 ft (1.8 m) above the floor. The ADPI should be equal to or greater than 80%.

Measuring the air velocity is more complicated and not usually done. For field analysis the ANSI/ASHRAE Standard 113-1990, *Method of Testing for Room Air Diffusion,* Appendix A states:

> *For summer (cooling) conditions the ADPI shall be equal to or greater than 80% and the test zone average air velocity (V,) shall not exceed 50 fpm (0.25 m/s).*

[Author's note: 50 fpm (0.25 m/s) maximum draft requirement indicates excellent performance. After all, walking past another person in a room creates a 75 fpm draft. (0.38 m/s)]

> *For winter (heating) conditions the ADPI shall be equal to or greater than 80%, the test zone average air velocity (V,) shall not exceed 30 fpm (0.15 m/s) and the maximum vertical air temperature difference (At,) shall not exceed 5°F (2.8°C).*

Airflow velocity measurements for drafts require specialized equipment. Confirming proper grille selection is more important and practical indicator than testing air velocity. If airflow testing is available, the measured velocity in the occupied area in all directions should be equal to or less than 30 fpm (0.15 m/s) for heating and 50 fpm (0.25 m/s) for cooling. Anemometers measure air velocity in a single direction. An omnidirectional anemometer is required to check air movements in all directions, but it is a delicate instrument.

If these conditions are not met, resolve the draft problems by modifying the grilles using ADPI criteria.

## Conclusion

The majority of hot/cold complaints can be diagnosed by observation, load calculations and recording thermometers.

The steps to investigating a hot/cold complaint are:

1. Define and validate the complaint;
2. Check the HVAC system equipment operation;
3. Calculate the building a space loads and verify that there is sufficient capacity;
4. Review zoning conflicts;
5. Test the zone for good and stable temperature control;
6. Review draft problems;
7. Measure the humidity level to verify it is below the Standard 55 upper dew-point limit of 62.2°F (16.8°C);

(Sometimes more rigorous and costly measures are necessary as explained in Items 8 and 9.)

8. Compare the load variation characteristics of the different spaces in each zone; and
9. Analyze the ADPI or measure the omni-directional drafts.

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## References

1. International Facility Management Association. 2003. Press release, "IFMA survey ranks top 10 office complaints…and some that score high on the laugh meter." www.ifma.org.
2. Martin, R.M., C.C. Federspiel, and D.M. Auslander. 2002. "Responding to thermal sensation complaints in buildings." *ASHRAE Transactions* 108(1).
3. ANSI/ASHRAE Standard 113-1990, *Method of Testing for Room Air Diffusion* Section 8.
4. ANSI/ASHRAE Standard 55-1992/55-2000R, Public Review Draft, *Thermal Environmental Conditions for Human Occupancy*, Section 5.2.4.3.
5. ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality* Appendix C.
6. *2001 ASHRAE Handbook—Fundamentals*, Chapter 32, Heating Load Principles.