## Singapore Chapter - ASHRAE Distinguished Lecture




- **Humidity Control Troubleshooting**
- **Humidity Control Design**
- **Suggestions for Buildings in Hot and Humid Climates**



**Lew Harriman, FASHRAE**
2011 - 2013 Chair TC 1.2 - Moisture Management in Buildings
Mason-Grant Consulting
Portsmouth, NH
**MasonGrant.com**

# Introduction - Attendees

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**What answers do you want.. before the end of the session?**

## Section 1 of 3

# Humidity Control Troubleshooting

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6. Summary

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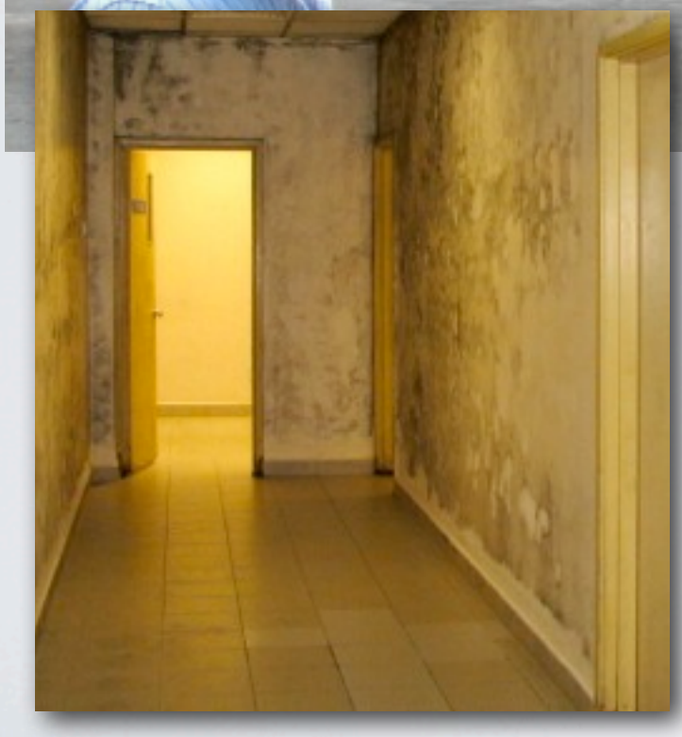

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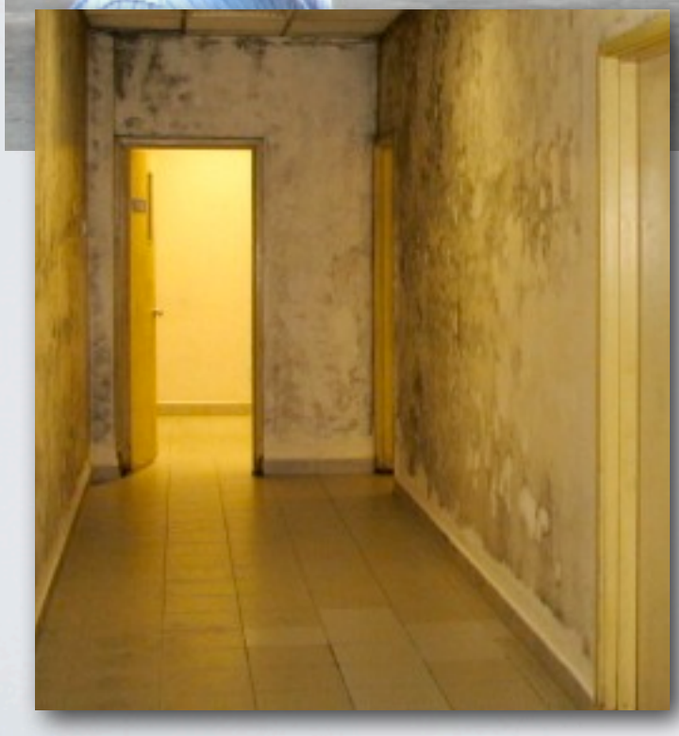



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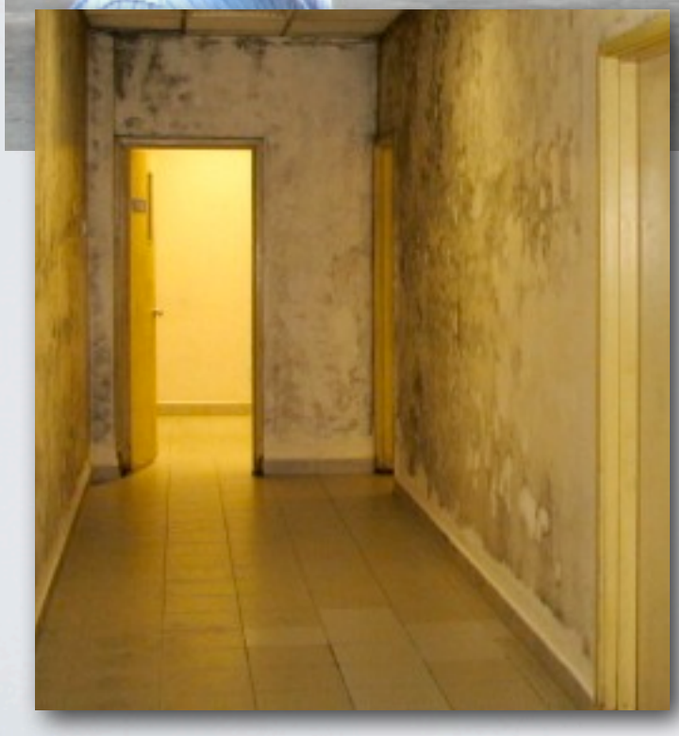





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- **NOT separate investigations for building and HVAC!**

# The voice of experience...
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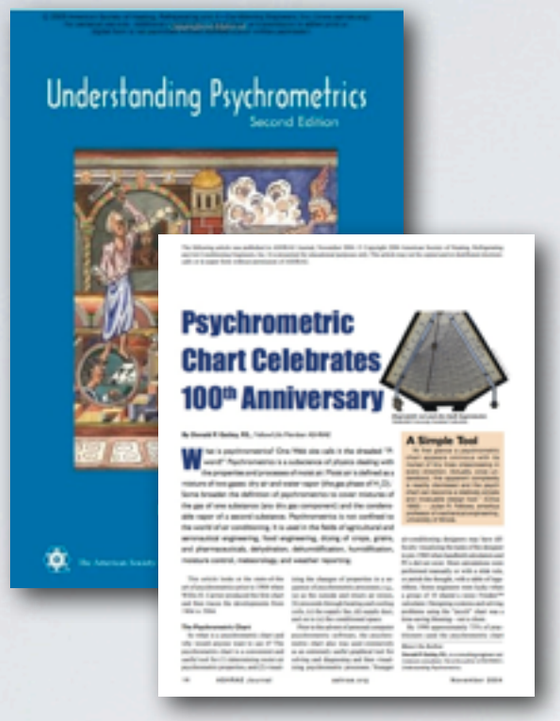


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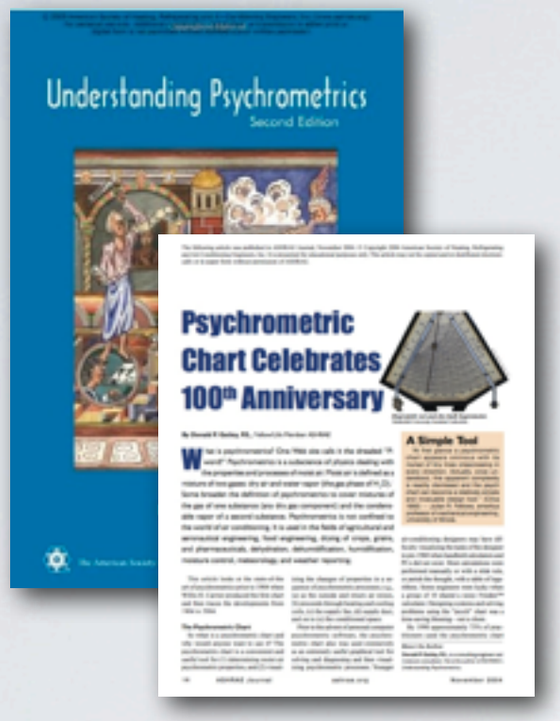


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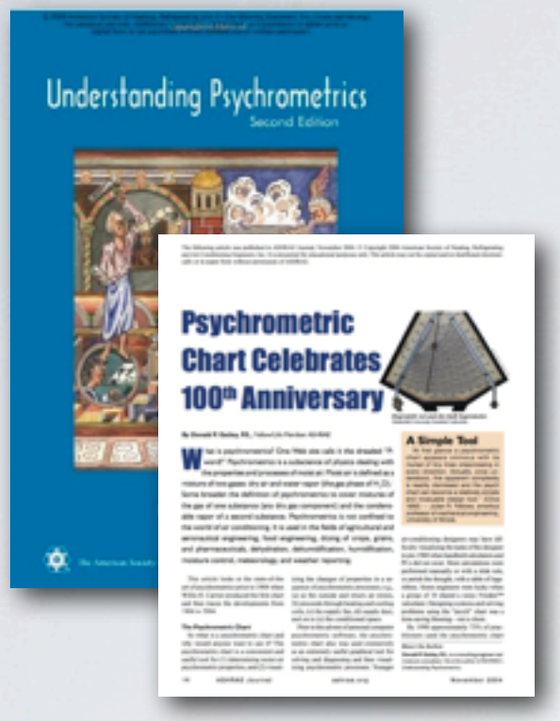


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**Don's advice: MOST HUMIDITY PROBLEMS ARE SIMPLE! Don't overcomplicate humidity troubleshooting. Make sure the building does not suck, and make sure the ventilation and makeup air is dry.**

# San Carlos Park Elementary School, Florida





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By Andrew C. Åsk, P.E., Member ASHRAE

# Ventilation and Air Leakage

Buildings leak water and air, which is normal and unavoidable. Therefore, designers should not fixate on preventing leakage, i.e., making buildings "airtight." Because even if all cracks were sealed, buildings have doors and windows.

Instead, the designer's goal should be to A) quantify leakage, B) reduce leakage if excessive, and C) control leakage by managing air pressures with the HVAC system. "Designer" in this case means at least two people—the architect and the HVAC engineer. It also may include the builder and building official. Until the building science engineer evolves as a separate discipline, primary responsibility for addressing building leakage will probably fall to the HVAC engineer.

A bicycle tire needs to hold air long enough to complete a journey in reasonable comfort, and lose no more air than can be replaced by the pump at hand. Although appearing airtight, the tire eventually will go flat. We should expect the same performance from the air barriers that help to form a building's pressure envelope.

So how much leakage is acceptable? The author suggests as a modest goal that buildings should leak no more than the air that must be introduced for acceptable indoor air quality.

The amount of outside air (OA) mandated by ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, is enough of a burden to the owner in terms of capital equipment cost and energy consumption. The owner should not need to provide even more OA to gain control of the indoor/outdoor pressure relationship.

**Building Pressurization**

Building air pressure with respect to outdoors should be neutral so that doors open and flue-gas vents function properly. However, should buildings be slightly positive or slightly negative? Most building scientists and mold remediation professionals now believe that wall and roof constructs should be pressurized from the cooler, dryer side. Dry air (with respect to the negative side) migrating through the wall absorbs moisture and tends to dry out the interstitial construction. Conversely, if hot, humid air is allowed to migrate through the construct, it can cool below its dew point and create condensation in the interstitial space, damaging building materials and allowing mold to grow.

With this principle in mind, buildings experiencing hot, humid weather should be positive with respect to the outside, and buildings in cold climates can be slightly negative. Experience has shown that designing for a very small pressure differential, (less than 0.01 in. w.c. [2.5 Pa] works well in hot, humid climates.

Wind currents will override pressurization this small. However, as wind shifts direction, it tends to cancel out its effects upon pressurization. This does not hold where one strong, wind direction prevails, such as by the sea. Cold climates will require a greater pressure differential, primarily due to stack effect.

"Leakage" in the natural, unplanned and uncontrolled flow of air into (infiltration) and out of (exfiltration) buildings. The artificial, intentional, controlled (hopefully) flow of air into buildings is called ventilation or outside air; the corresponding outward flow is exhaust. These intentional flows must work in concert with natural leakage.

The relationship between OA, exhaust, and leakage can be expressed with simple arithmetic:

**Building Positive, Hot, Humid Climate:**

Outside Air = Exhaust + Leakage (Exfiltration)

**About the Author**
**Andrew C. Åsk, PE.**, is an HVAC and IAQ consultant in Cape Coral, Fla.



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1.0 ACH cfm = V/60

Then, based upon the practitioner's experience, estimate an infiltration rate in terms of a fraction of ACH. The author, for example, has allowed between 0.50 and 1.0 ACH for "infiltration" throughout his career with reasonable success. Post-1973 buildings built to ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, requirements might be as tight as 0.25 ACH. Antiquated factory buildings on the other hand could experience 2 or more ACH.

Why did I use between 0.50 and 1 ACH? Because my HVAC professor at Iowa State told me to in 1962. All I had to go on was his direction, *Manual J*, and one tattered ASHRAE Handbook shared by the entire class. I had no need to question my assumption until 25 years later, when I was unable to heat a factory in Fargo, N.D., which had fenestration that had not been fixed for the past 55 years — its air apparently changed three times each hour. A few years later, I found that I couldn't dehumidify buildings in southwest Florida. I suspected there had to be better ways to estimate building leakage. There were.

Air change rates (ACH) continue to be a good way to express building leakage, but coupled with a pressure differential, normally 0.20 in. w.c. (50 Pa). A building would never operate (intentionally) at this pressure, but they can be more accurately tested at this high pressure (for the same reason that a damper or valve must experience a high-pressure differential before it can provide close control). The ACH rate at 0.20 in. w.c. (50 Pa) is interpolated to the actual building pressure desired (say 0.01 in. w.g. [2.5 Pa]) to determine how much air will be required for pressurization. The astute HVAC engineer should begin to see a relationship that looks like a constant mechanical duct system whose behavior can be predicted by

**Building Negative, Cold Climate:**

Outside Air = Exhaust – Leakage (Infiltration)

HVAC engineers can readily calculate how much outside air is required for acceptable ventilation as prescribed in Standard 62, and how much exhaust is required for toilets, showers, hoods, etc.

Building leakage is a bit more elusive. The goal of this article is to discuss the methods for measuring and expressing leakage, and to report the results of a case study, San Carlos Park Elementary School, in Ft. Myers, Fla.

**Quantifying and Expressing Leakage**

Perhaps the oldest (and worst) method for estimating building leakage was the "crackage" method, where the width of cracks around windows and doors was estimated, a cfm per linear foot of crack allowance assumed, and infiltration estimated by extending these computations.

A better (and certainly much easier) method is to begin by computing the volume of a building in $ft^3$ and then divide that number by 60 as an expression of the cfm airflow required to "change" the air in an hour's time (ACH):



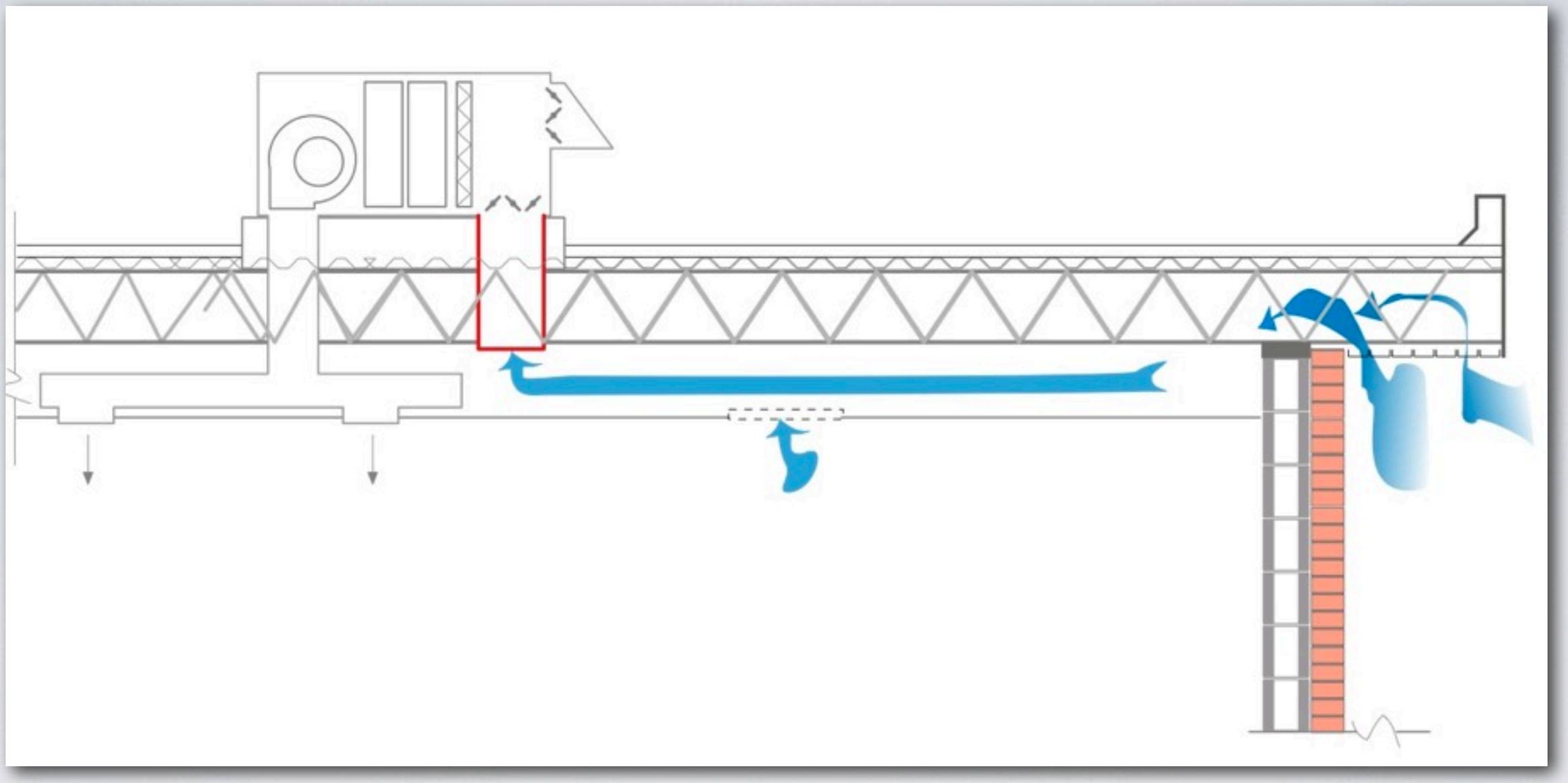
Andy Åsk - ASHRAE Journal - November 2003

# Problems



- "Poor indoor air quality" (moldy odors)
- Comfort complaints - damp and muggy
- AC system can't maintain temperatures
- High energy costs

# Low-cost HVAC design - Return air plenums



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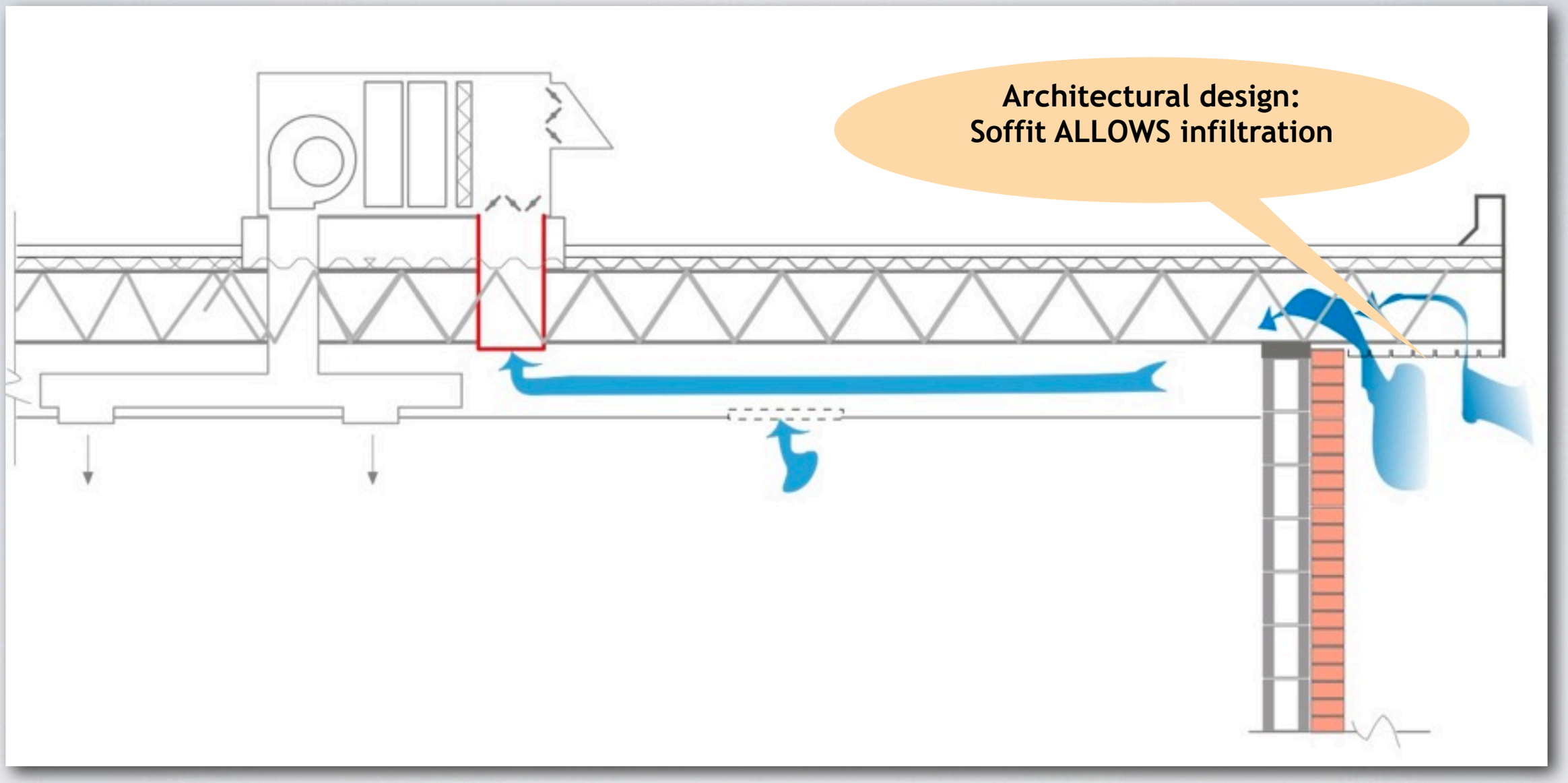

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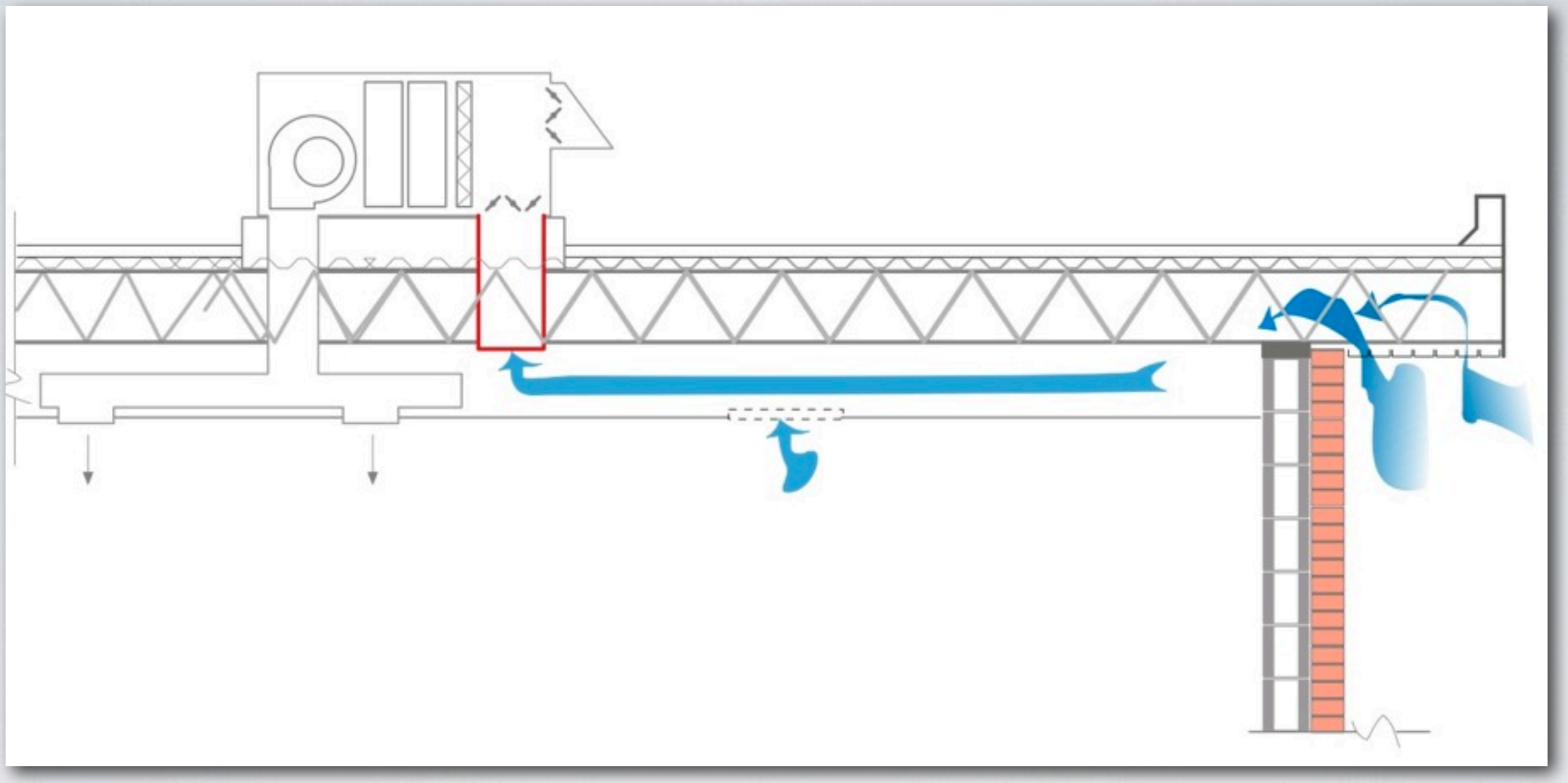

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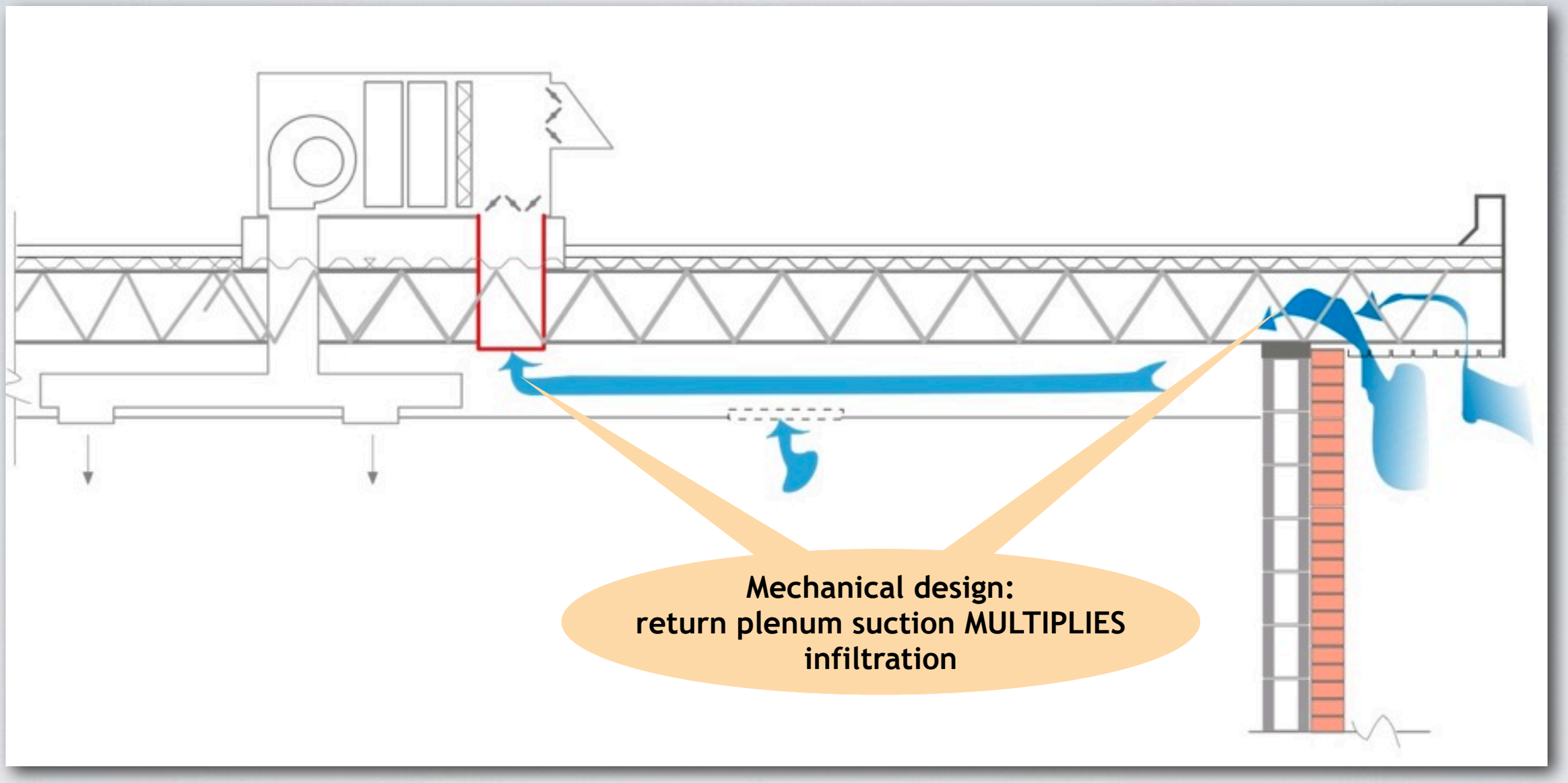

# Architectural and HVAC shortcomings combine to cause big problems

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| **Before Remediation** | 7,300 cfm | **408** | 42,000 cfm | **2,349** |

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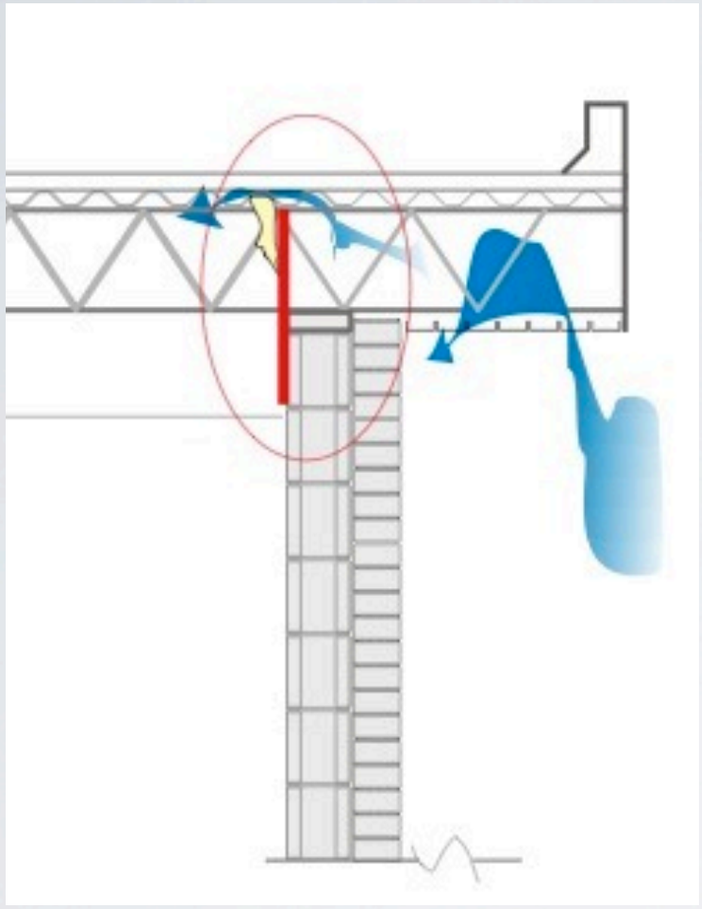
**Note the SIZE of the unexpected load when systems ARE operating...!**

# Retrofit Solution



- Added gypsum board between the wall and roof deck.
- Sealed the gypsum board to the roof deck with spray foam to avoid labor-intensive cutting and fitting.
- Protected spray foam with a layer of spray-on intumescent, fire-rated sealant
- Net result... 55% reduction in passive (system off) air infiltration

# Troubleshooting Sequence and Procedures

1. Traditional troubleshooting procedures, with a brief example of why they do not work.

2. The essence of humidity control troubleshooting - Loads vs. DH capacity

3. Troubleshooting sequence and procedures
   a. Investigate and understand the problems
   b. Measure the loads
   c. Measure the DH capacity
   d. Understand the controls
   e. Plan the solution

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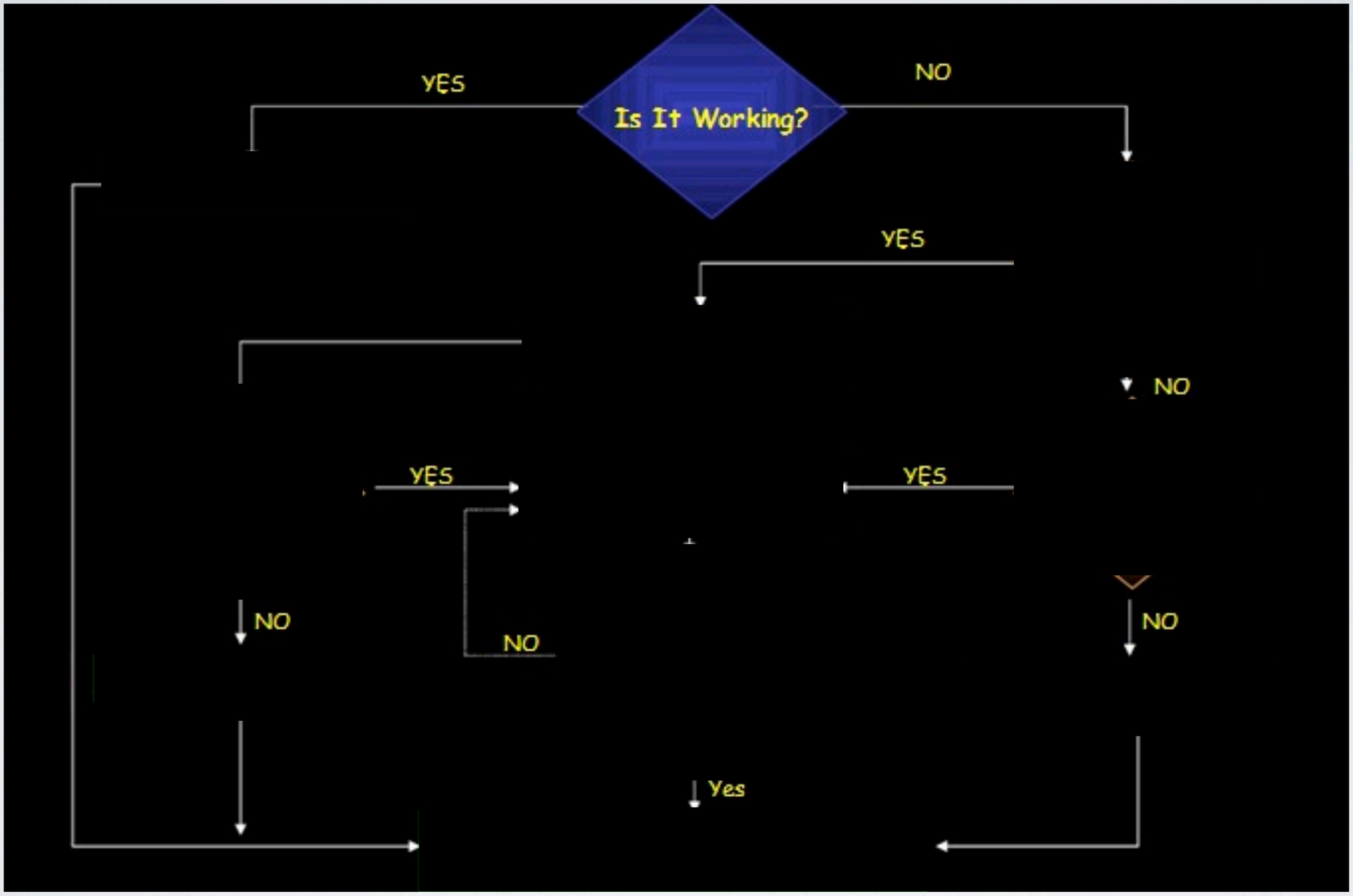

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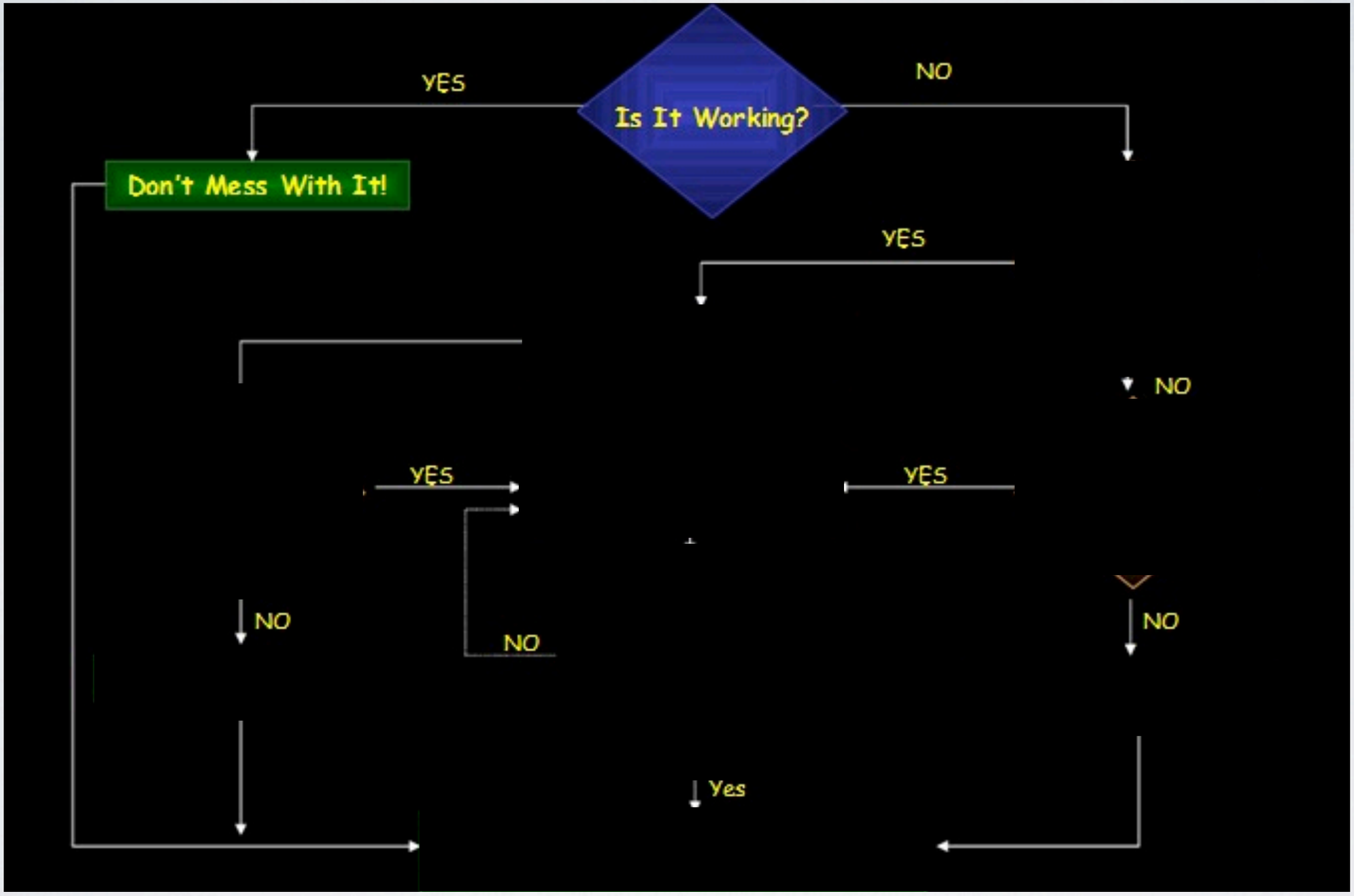

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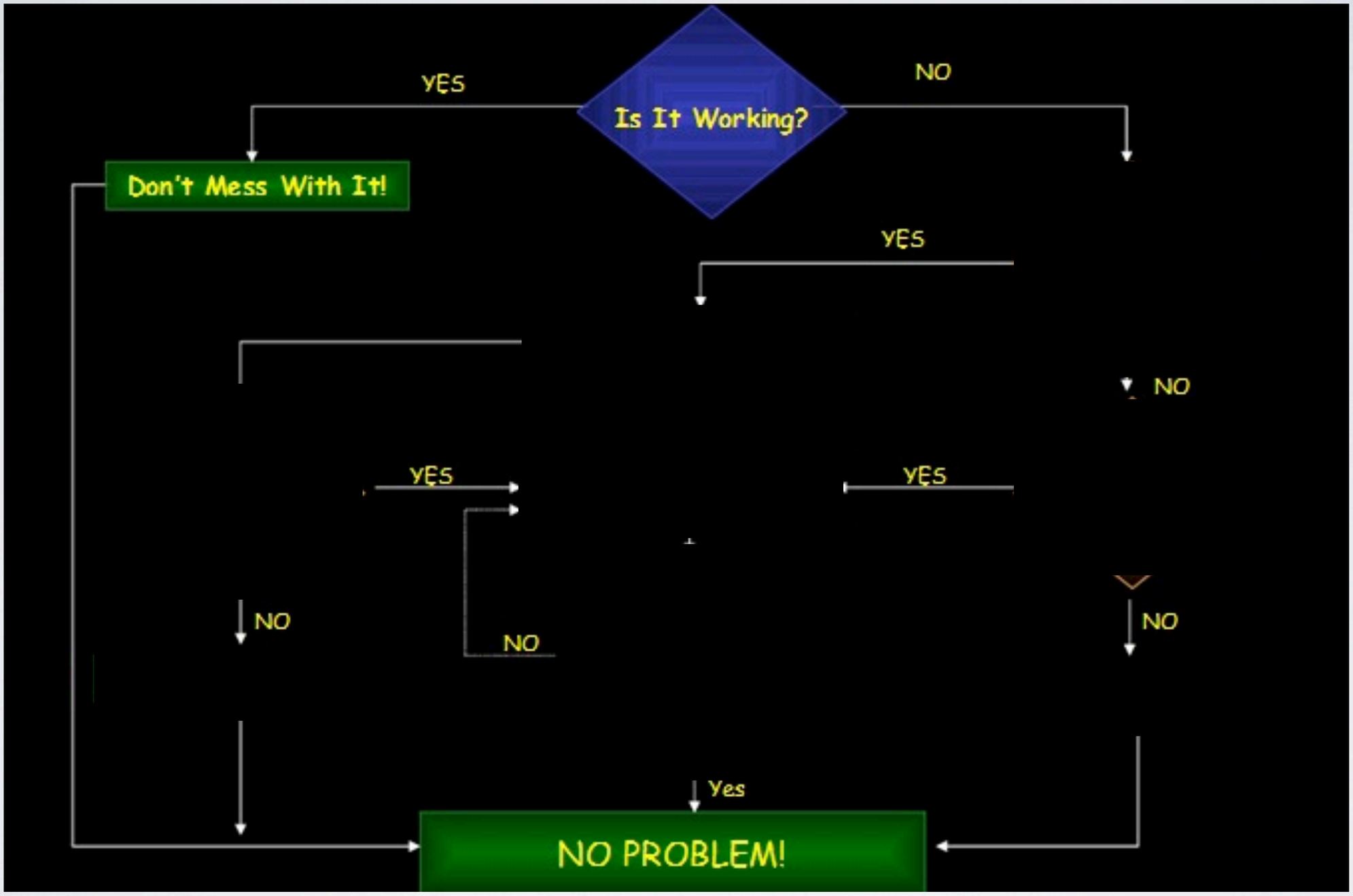

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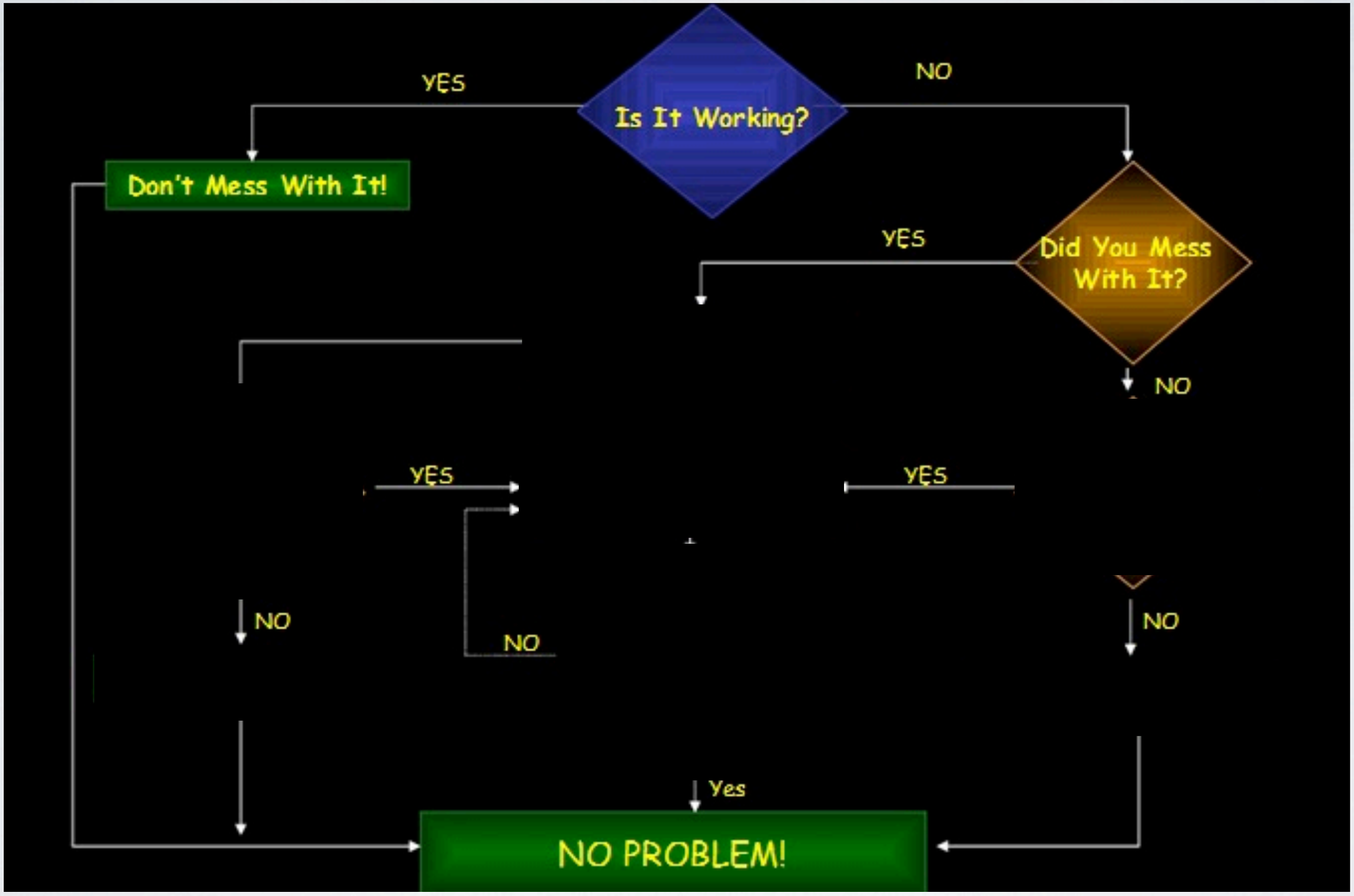

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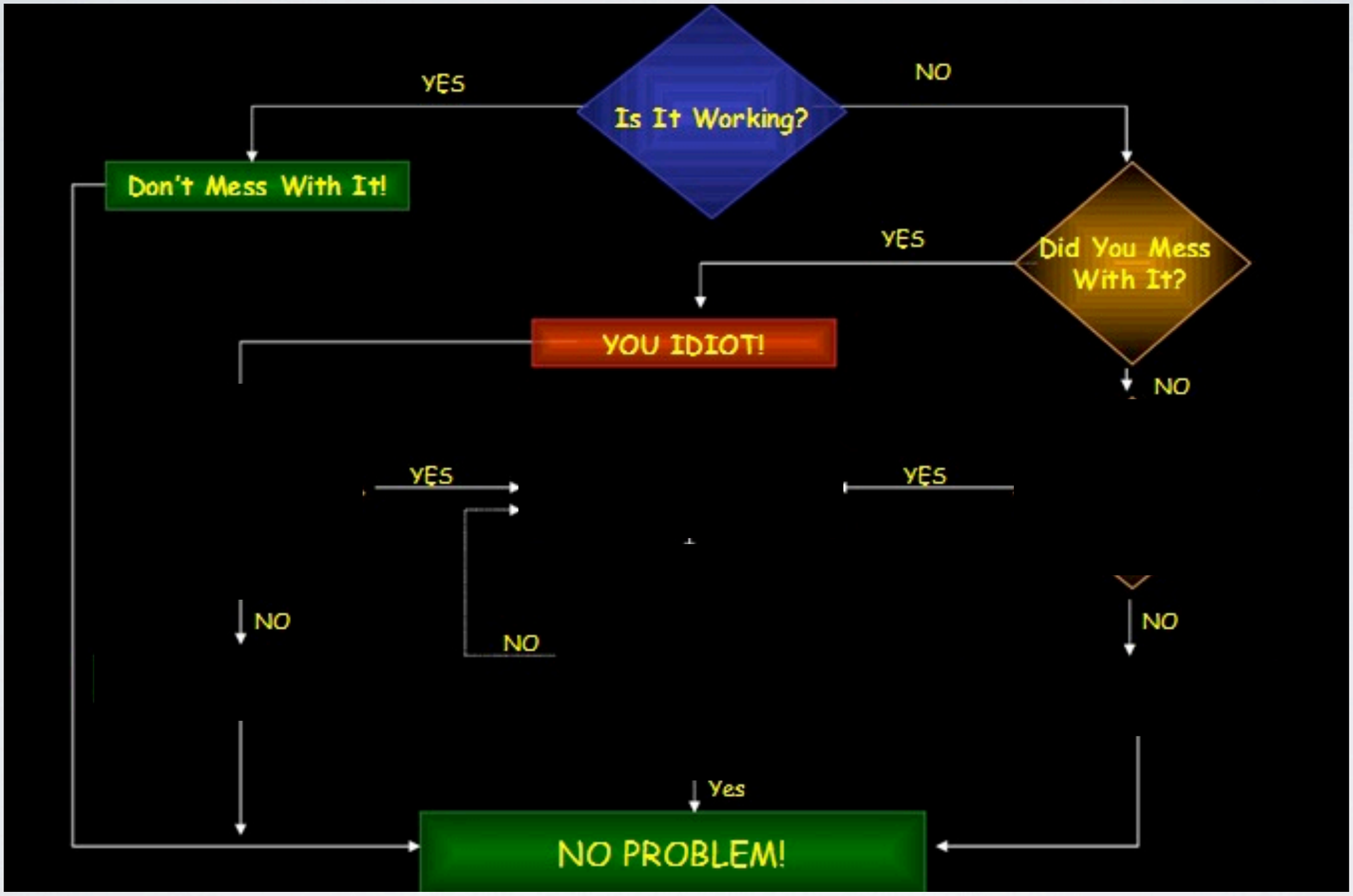

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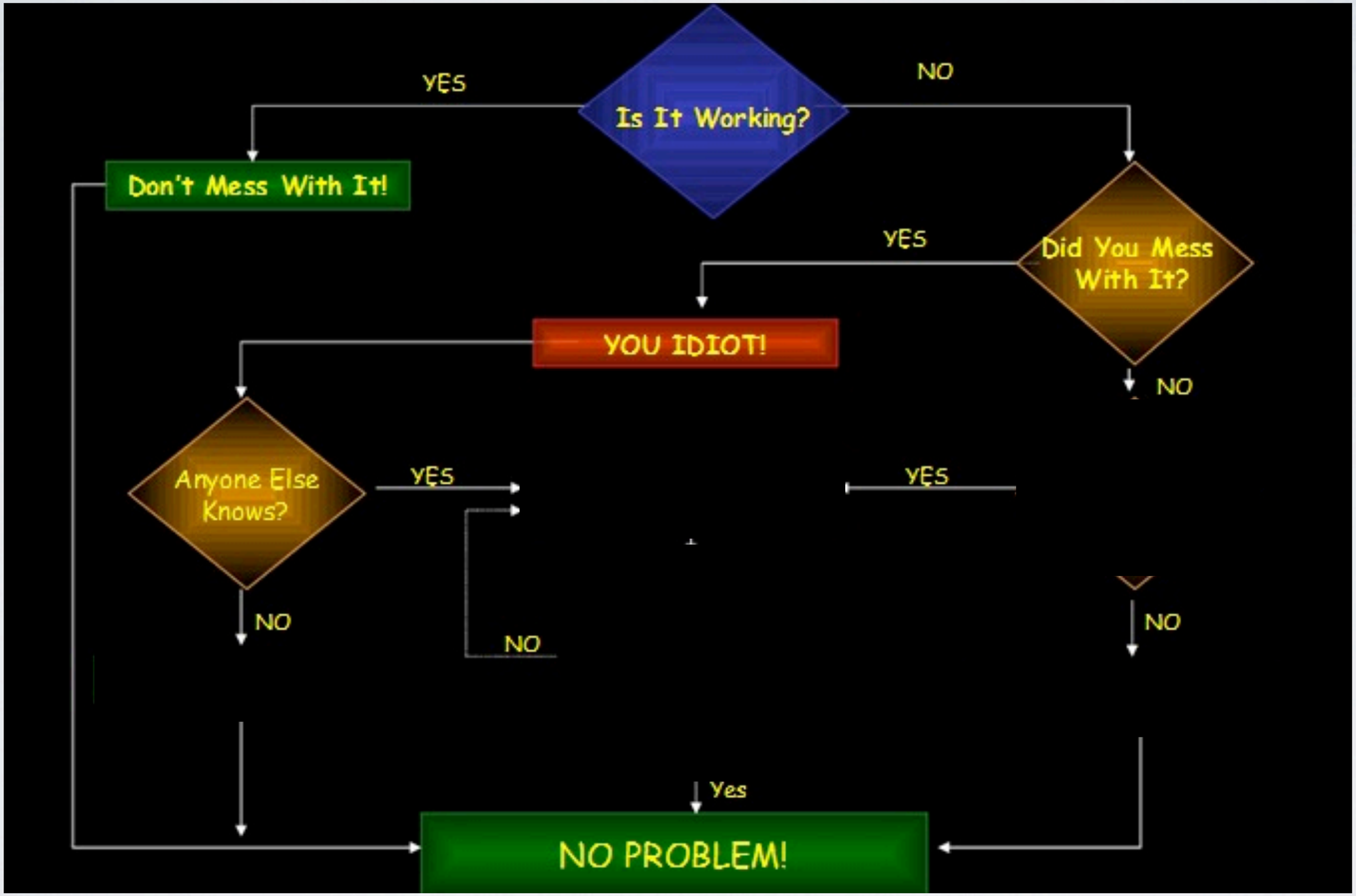

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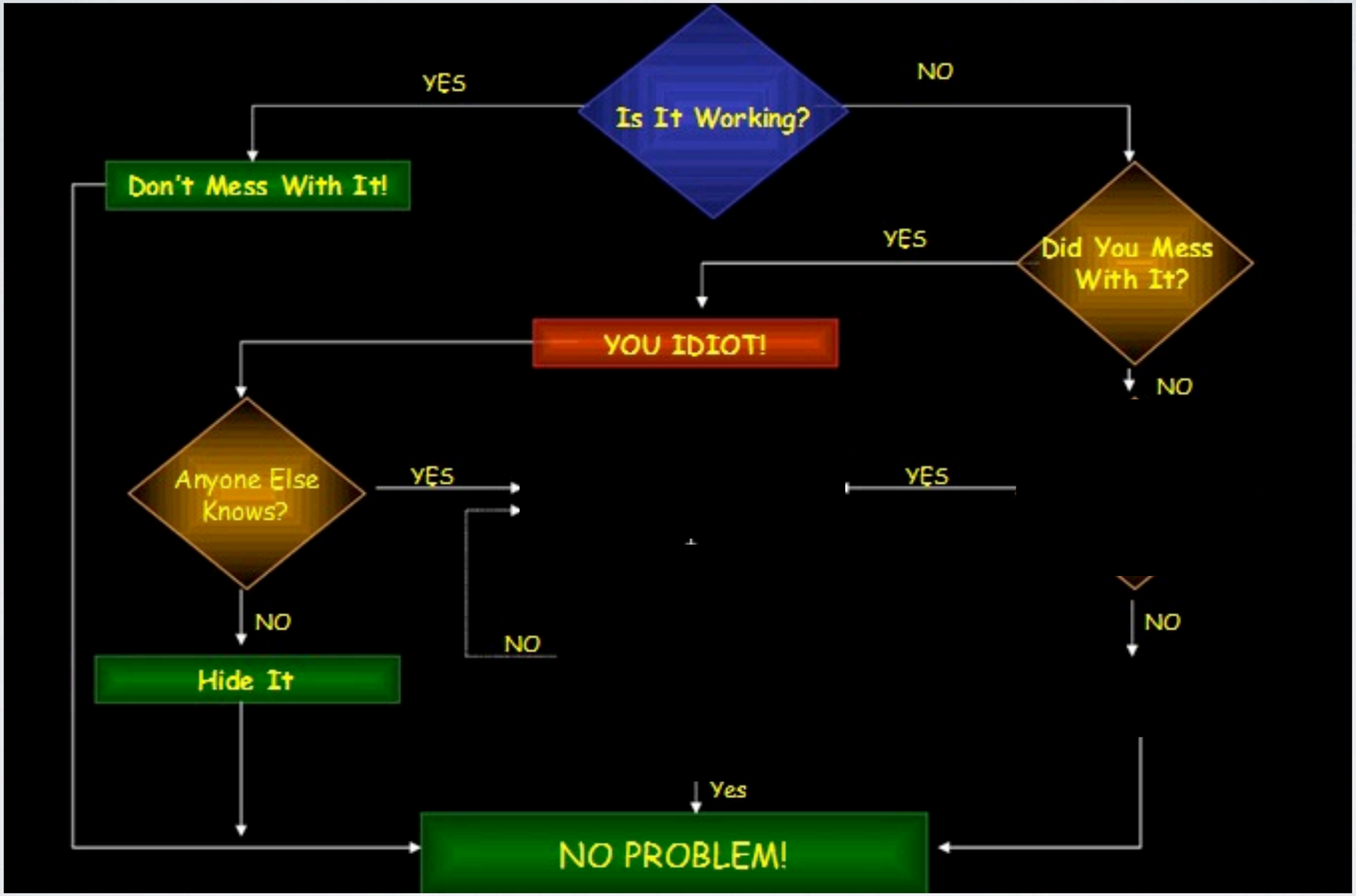

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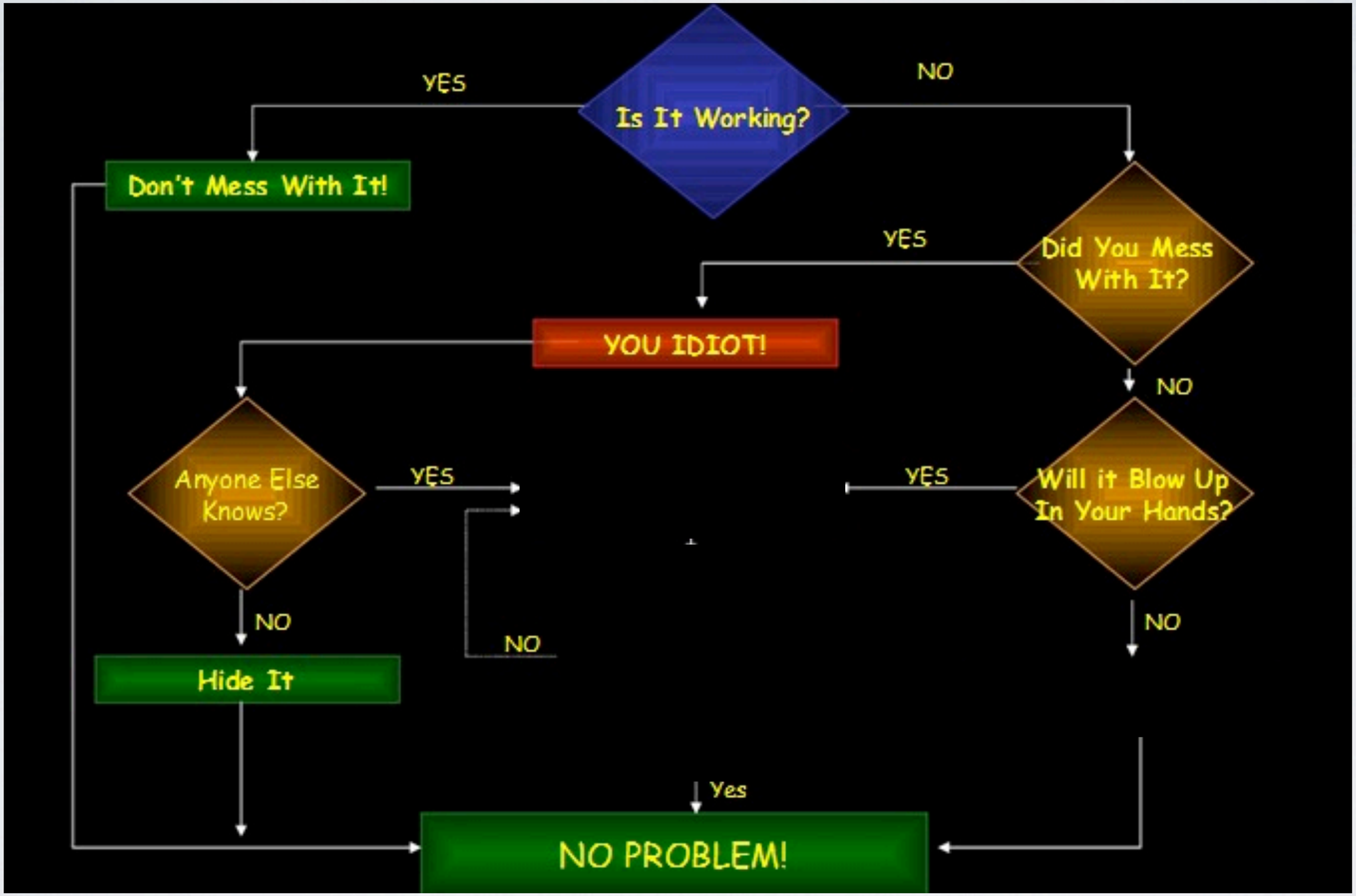

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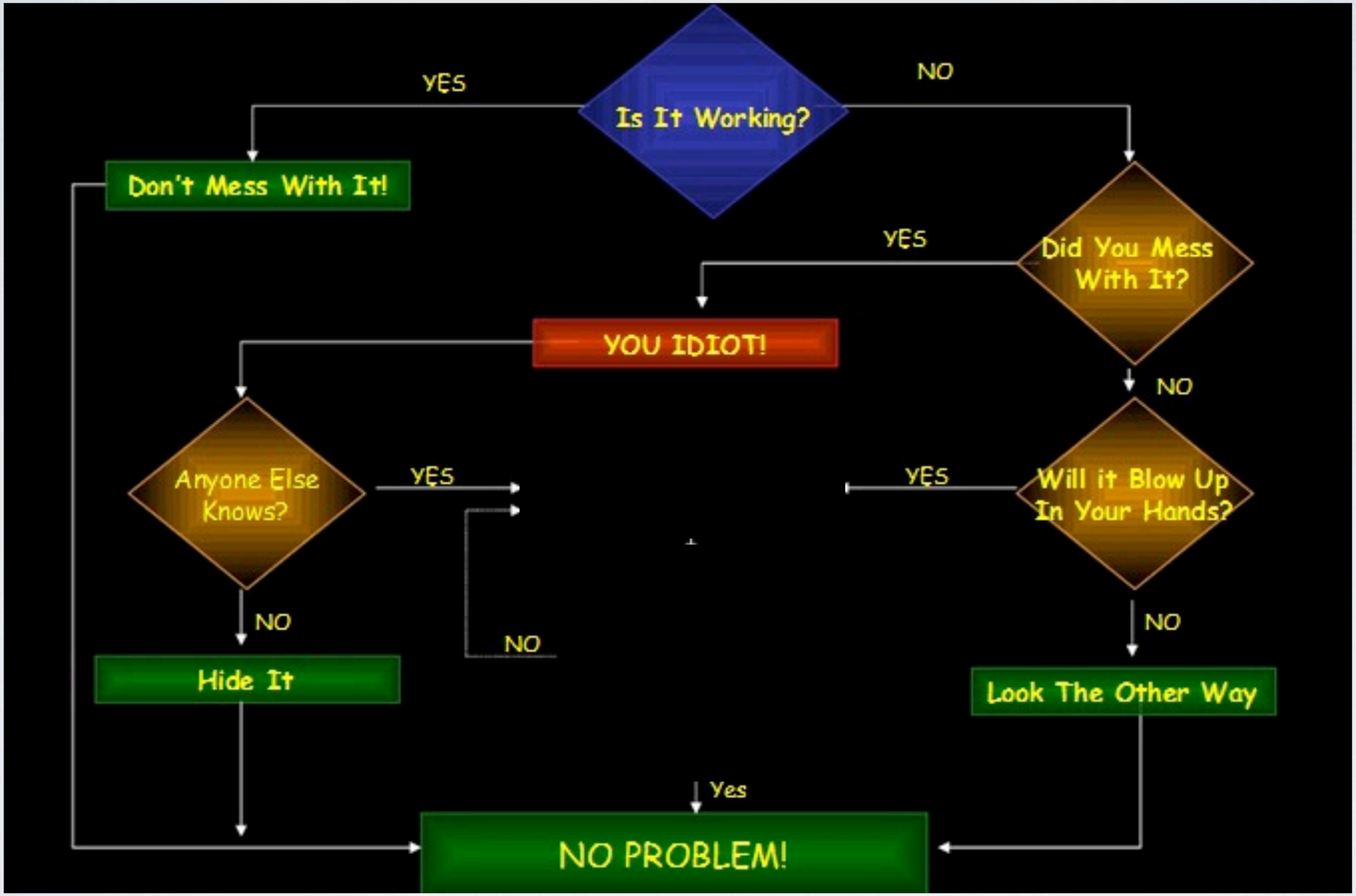

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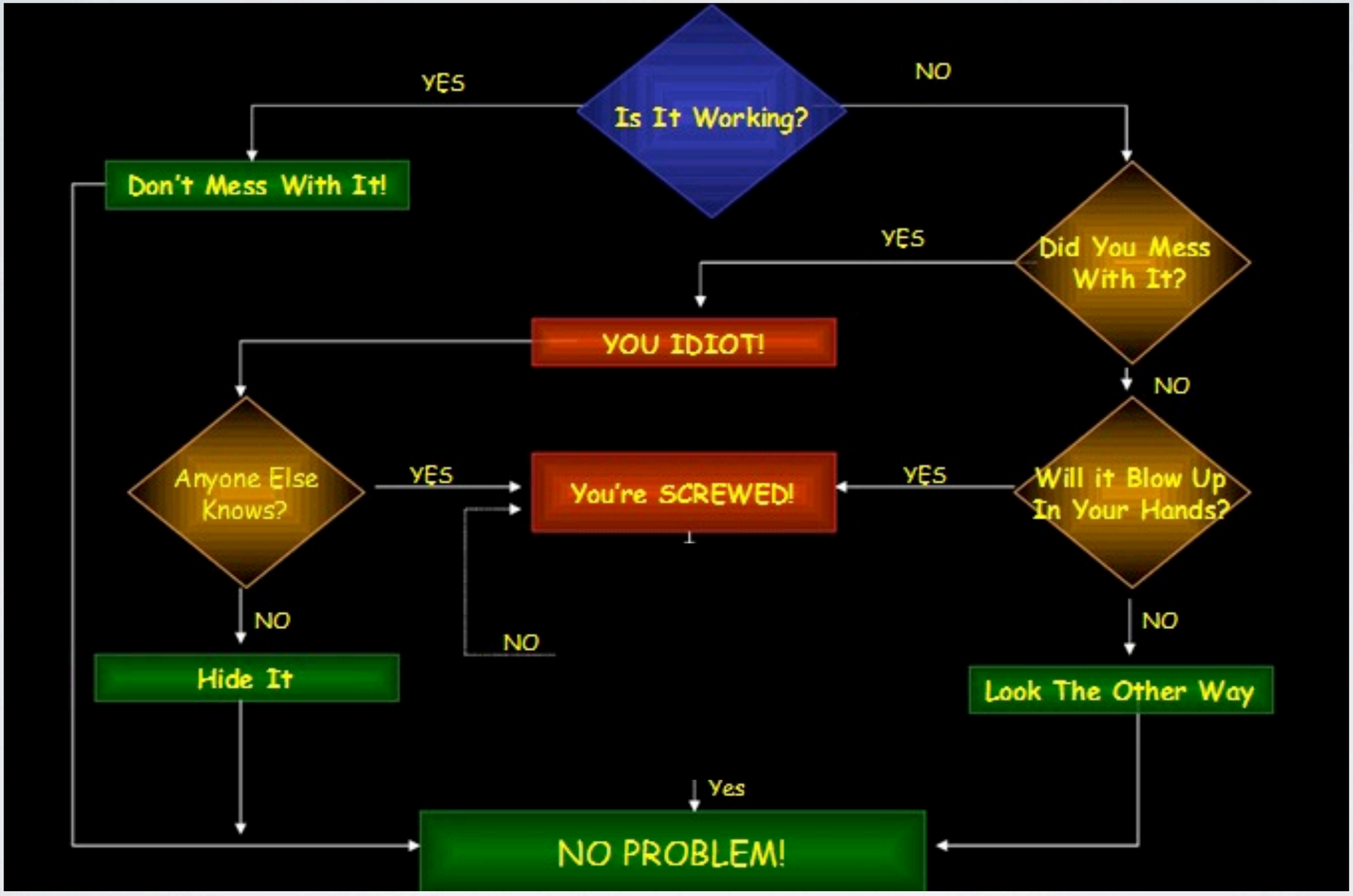

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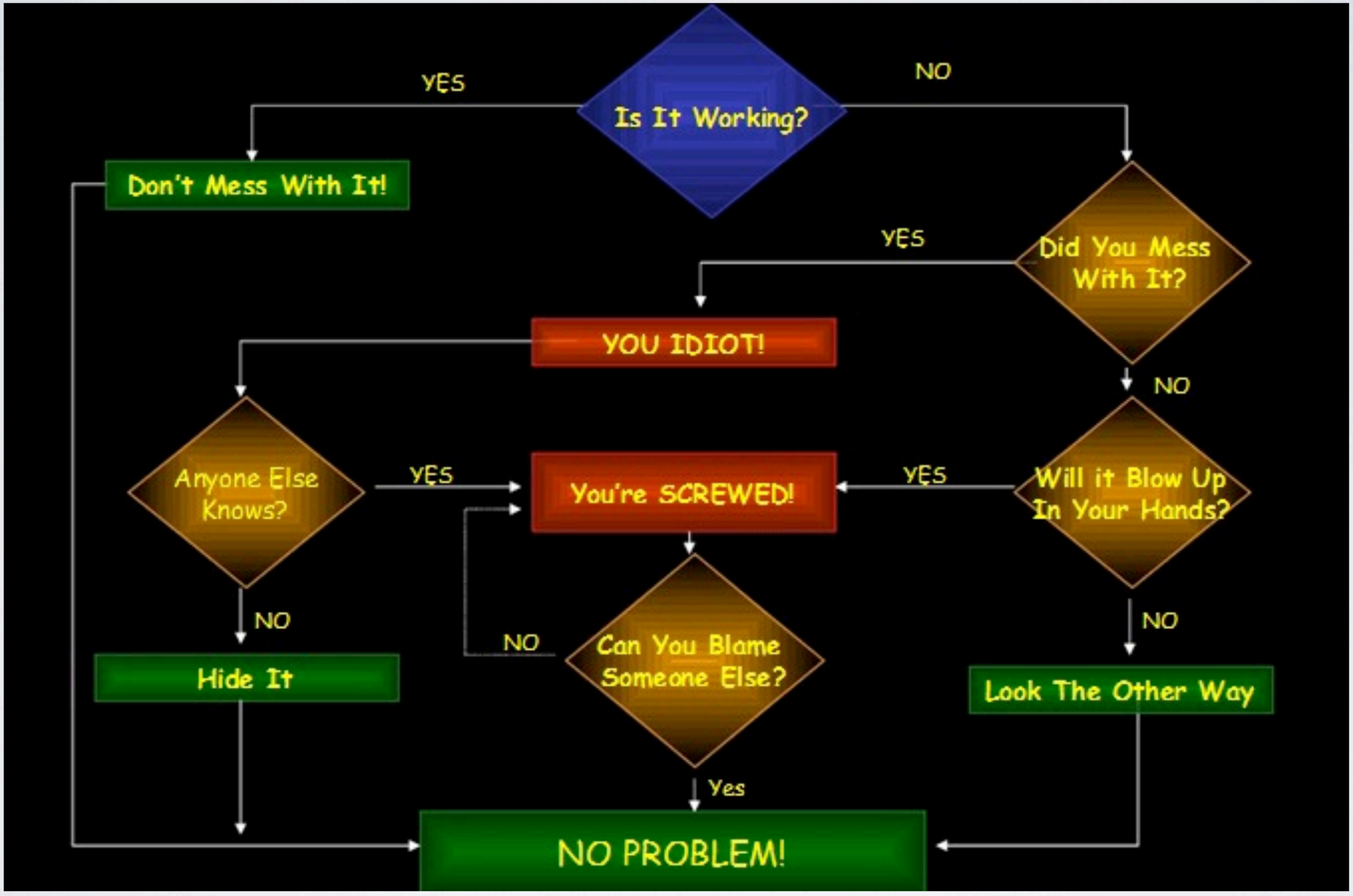

# The essence of humidity control troubleshooting

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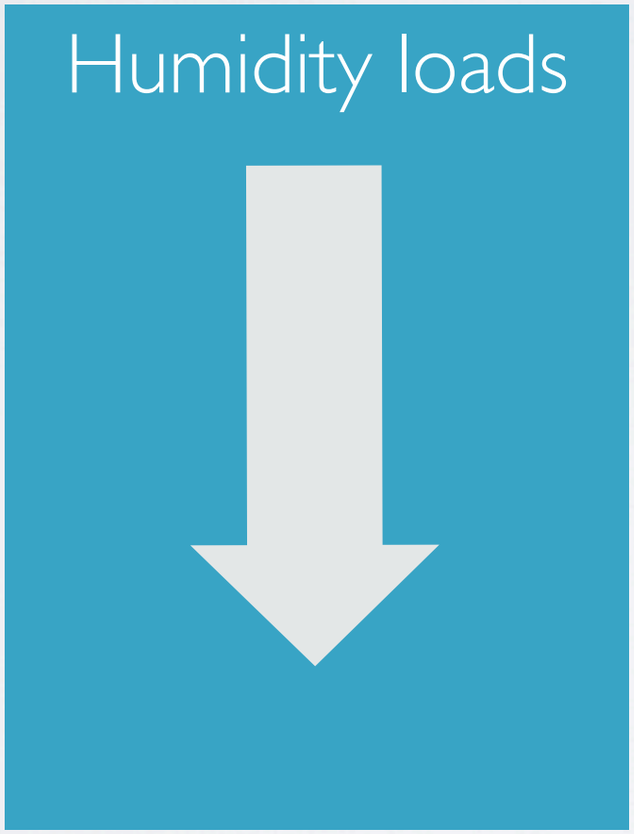

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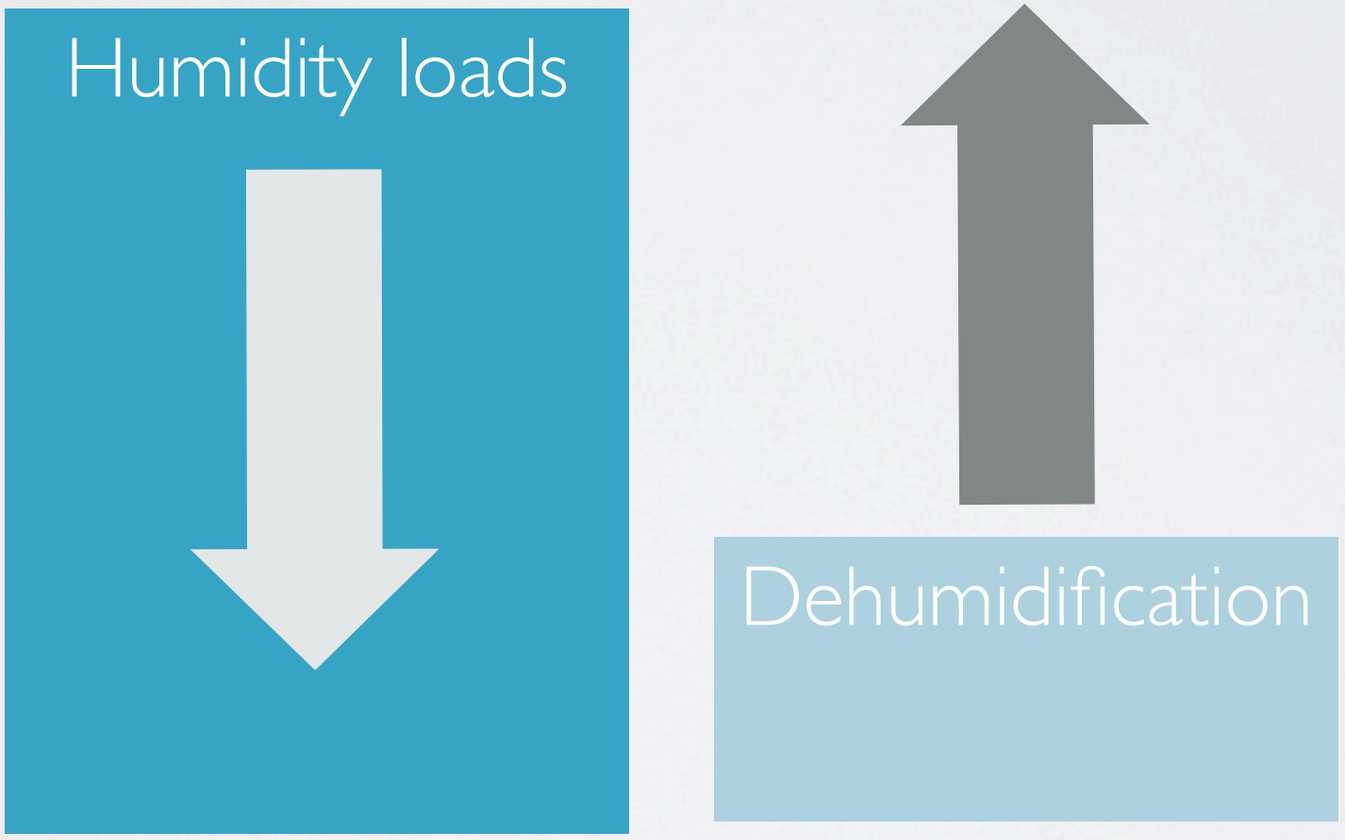

# Troubleshooting sequence

1. Listen and understand the problems

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4. Measure the key variables
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   b. The dehumidification

5. Diagnose the problems... plan solutions

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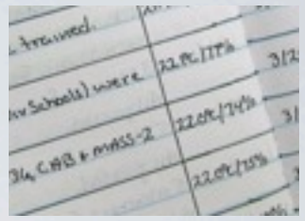

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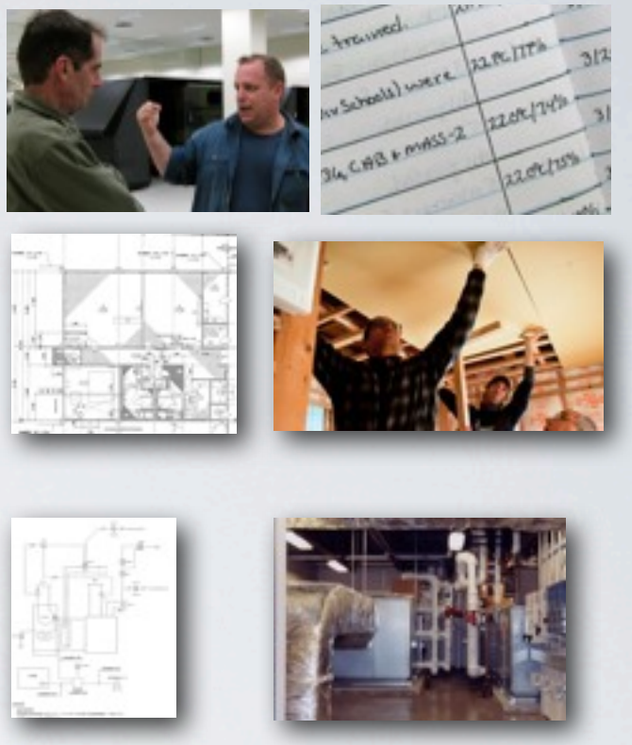

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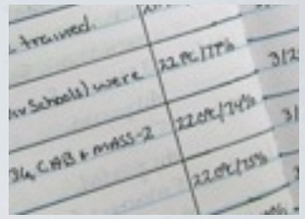





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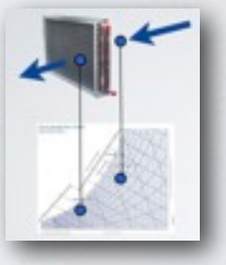

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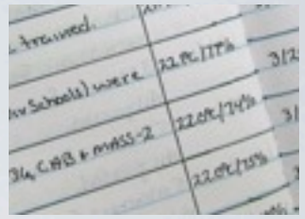

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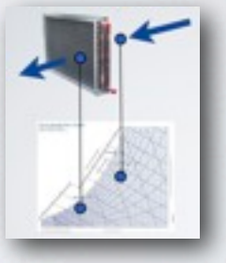

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2. Review the building drawings. Then walk through the building and around it, to understand the enclosure.
3. Review the HVAC drawings, equipment schedules and controls, then walk around, to understand the DH capacity.

# Then... start thinking about the problems



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# Next, MEASURE **loads**...
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- Humidity loads
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## Dehumidification

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Humidity loads

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**How to measure?**

**Flow Hood**

# Measuring humidity loads - Exhaust air flow

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**How to measure?**

**Flow Hood**



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**How to measure?**

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How to measure?

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**Building air leakage**

Number of people

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How to measure?

**Blower door**

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How to measure?

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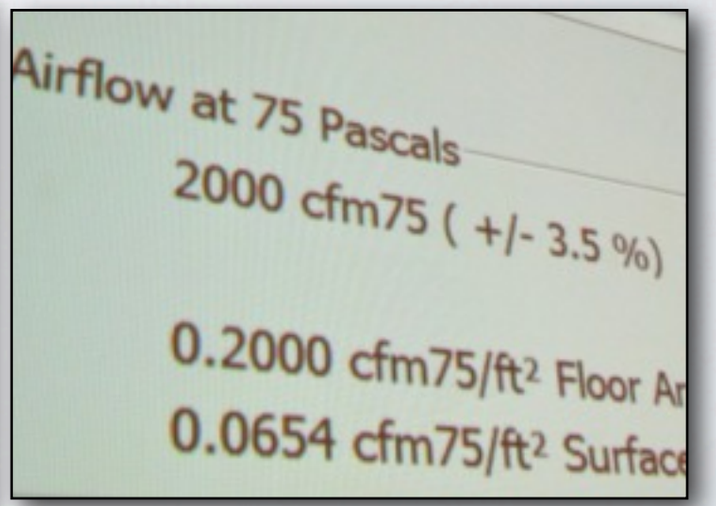

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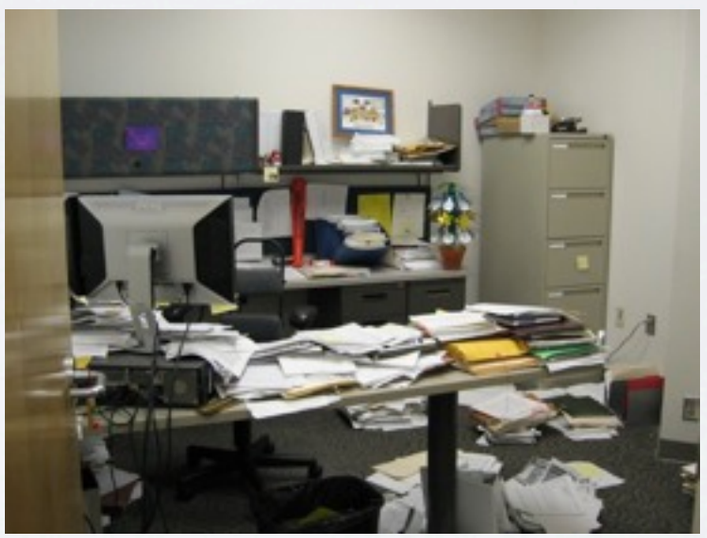





# Measuring humidity loads - Wet surfaces

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Dehumidification

Humidity removal

Dry air flow

Controls

# Measuring Dehumidification - Humidity removal

Dehumidification

Humidity removal

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**First..**
**Find the**
**Dehumidifier!**

Dehumidification

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Dry air flow

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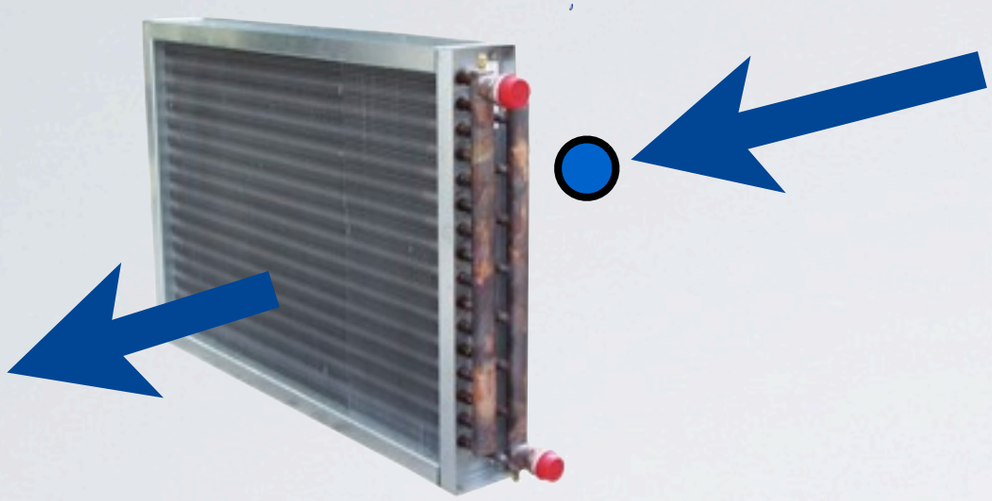

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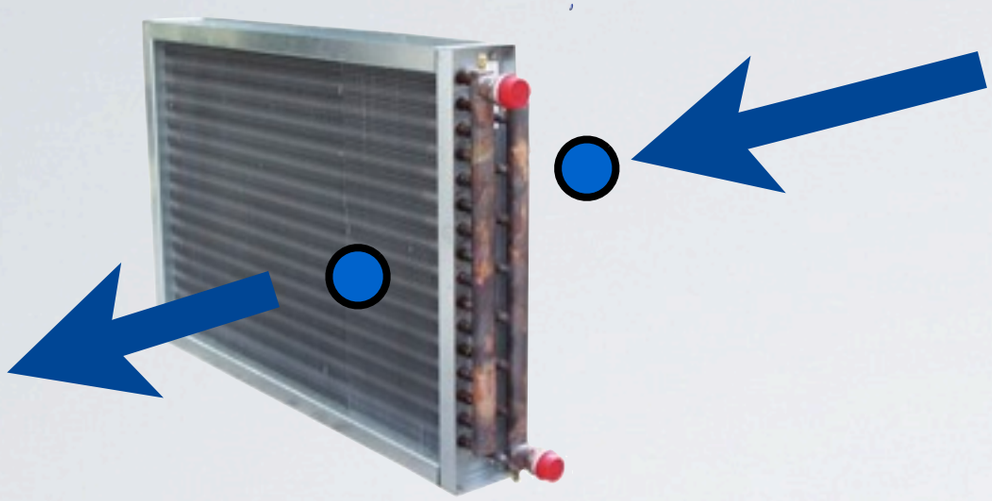

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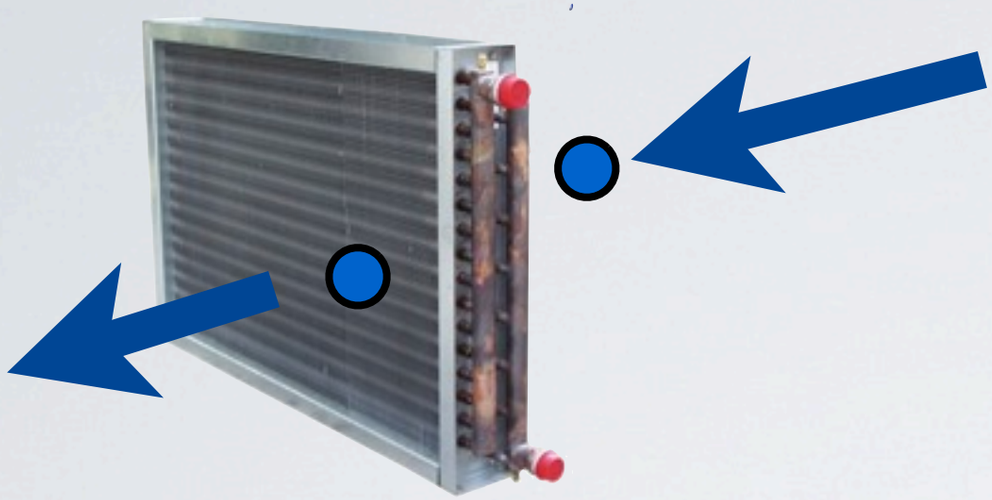

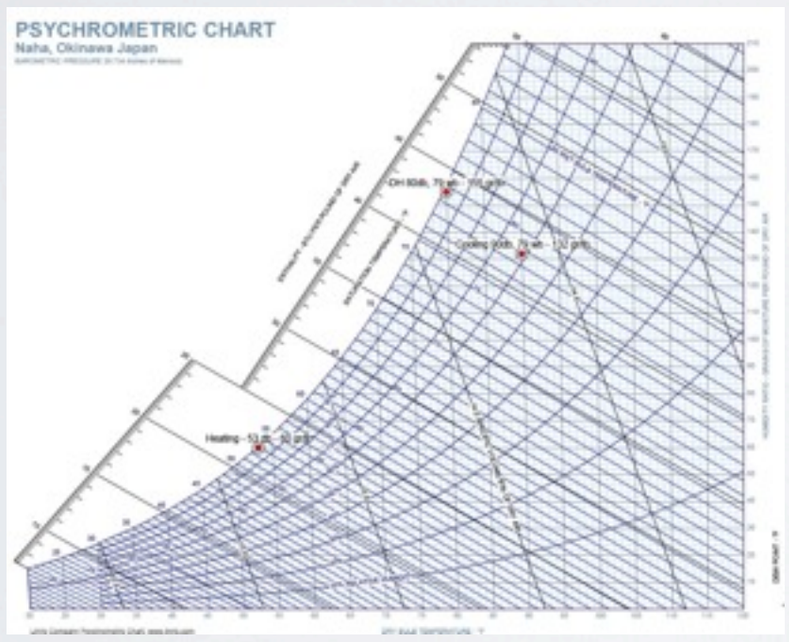


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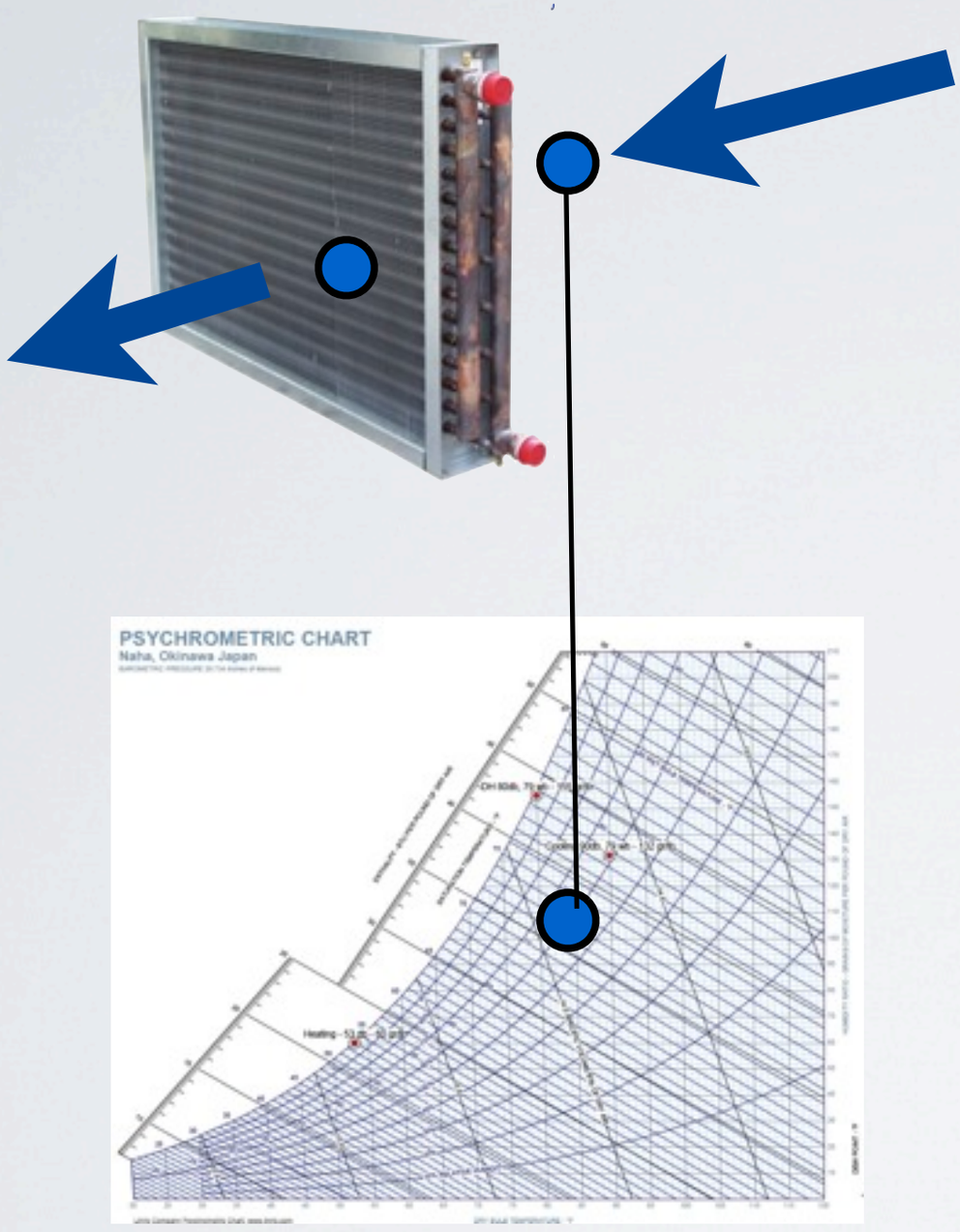


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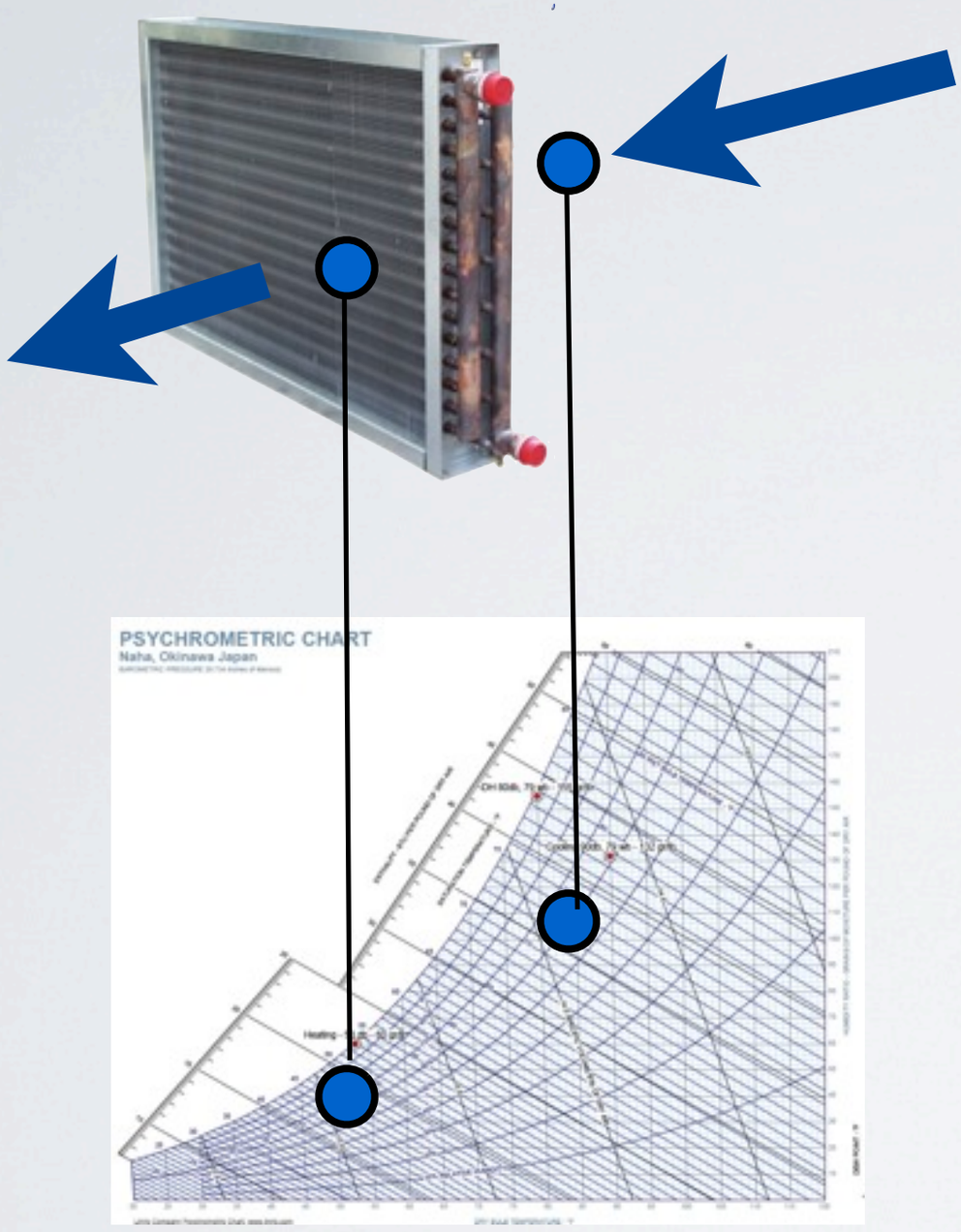


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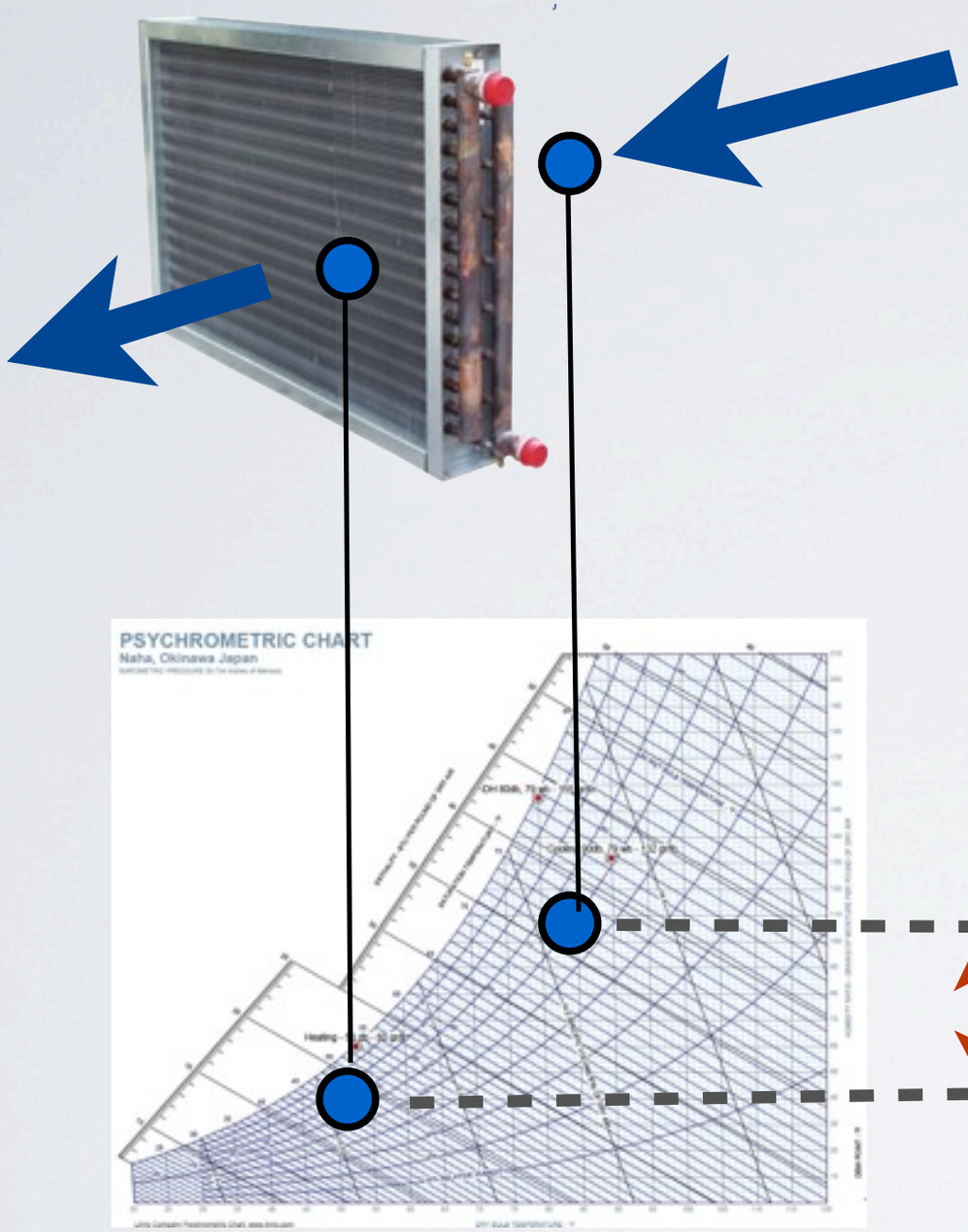


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Dehumidification

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**How to measure?**

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Dehumidification

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**How to measure?**

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Dehumidification

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How to measure?

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Dehumidification

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## How to measure?

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Dehumidification

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How to measure?

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How to measure?

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# Measuring Dehumidification - Dry air flow









Dehumidification

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How to measure?

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# Measuring Dehumidification - Dry air flow



Dehumidification

Humidity removal

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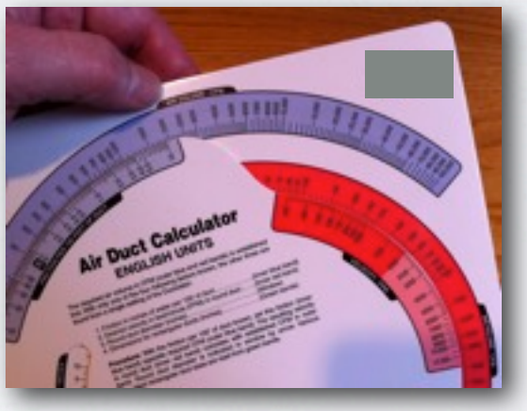


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Dehumidification

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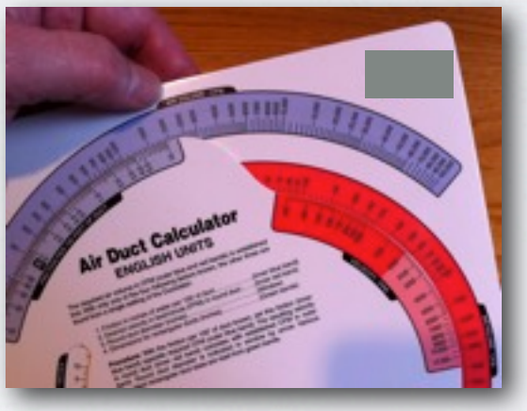





How to measure?

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# Measuring Dehumidification OVER TIME - Controls

Dehumidification

Humidity removal

Dry air flow

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# Measuring Dehumidification OVER TIME - Controls

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Humidity removal

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**Do they really work?**

**Review diagrams, place dataloggers**

**..then compare to the real world**

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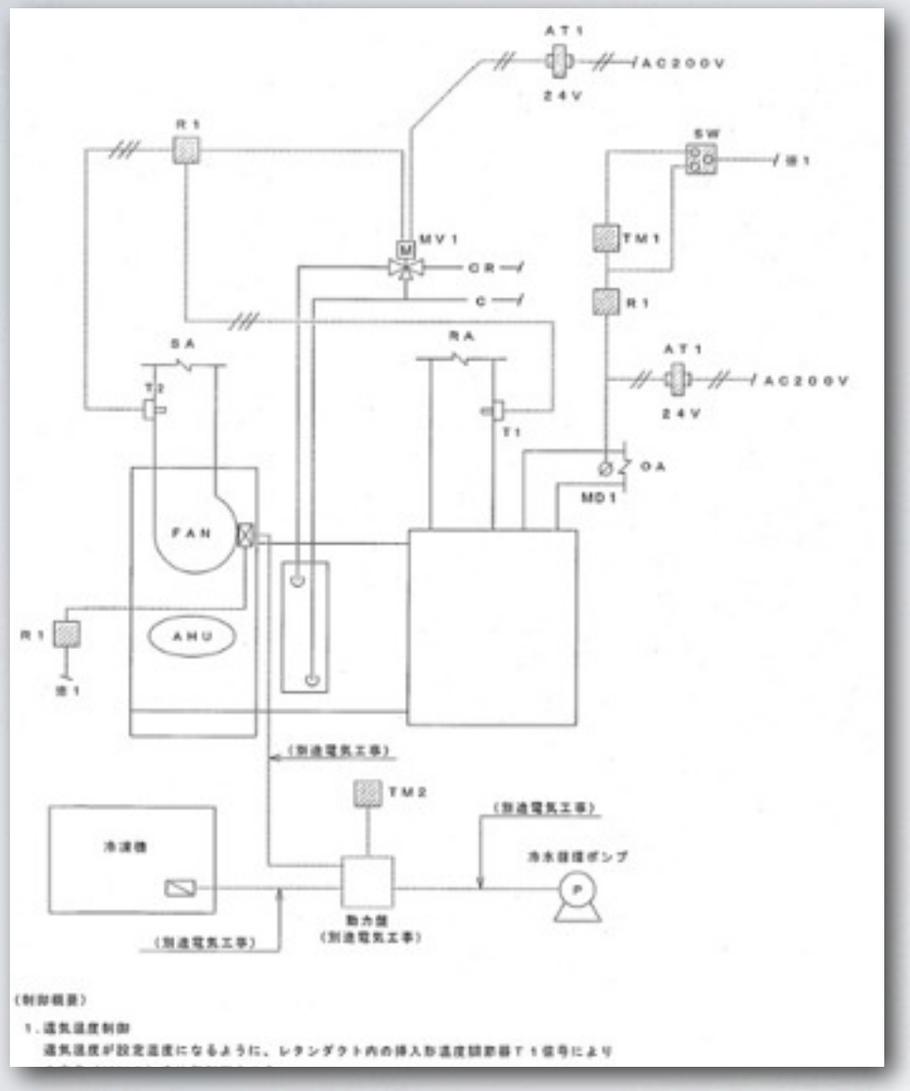


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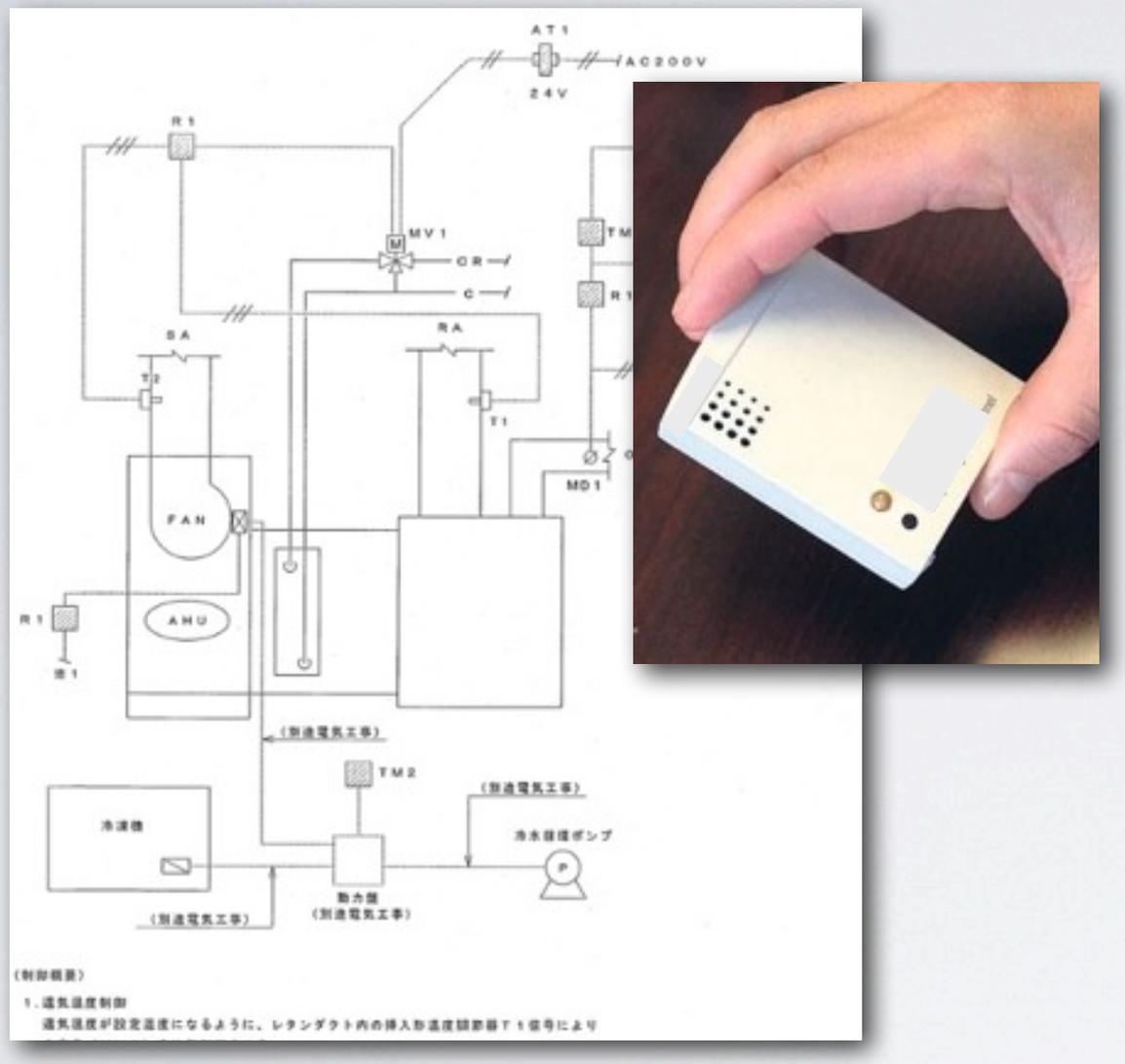




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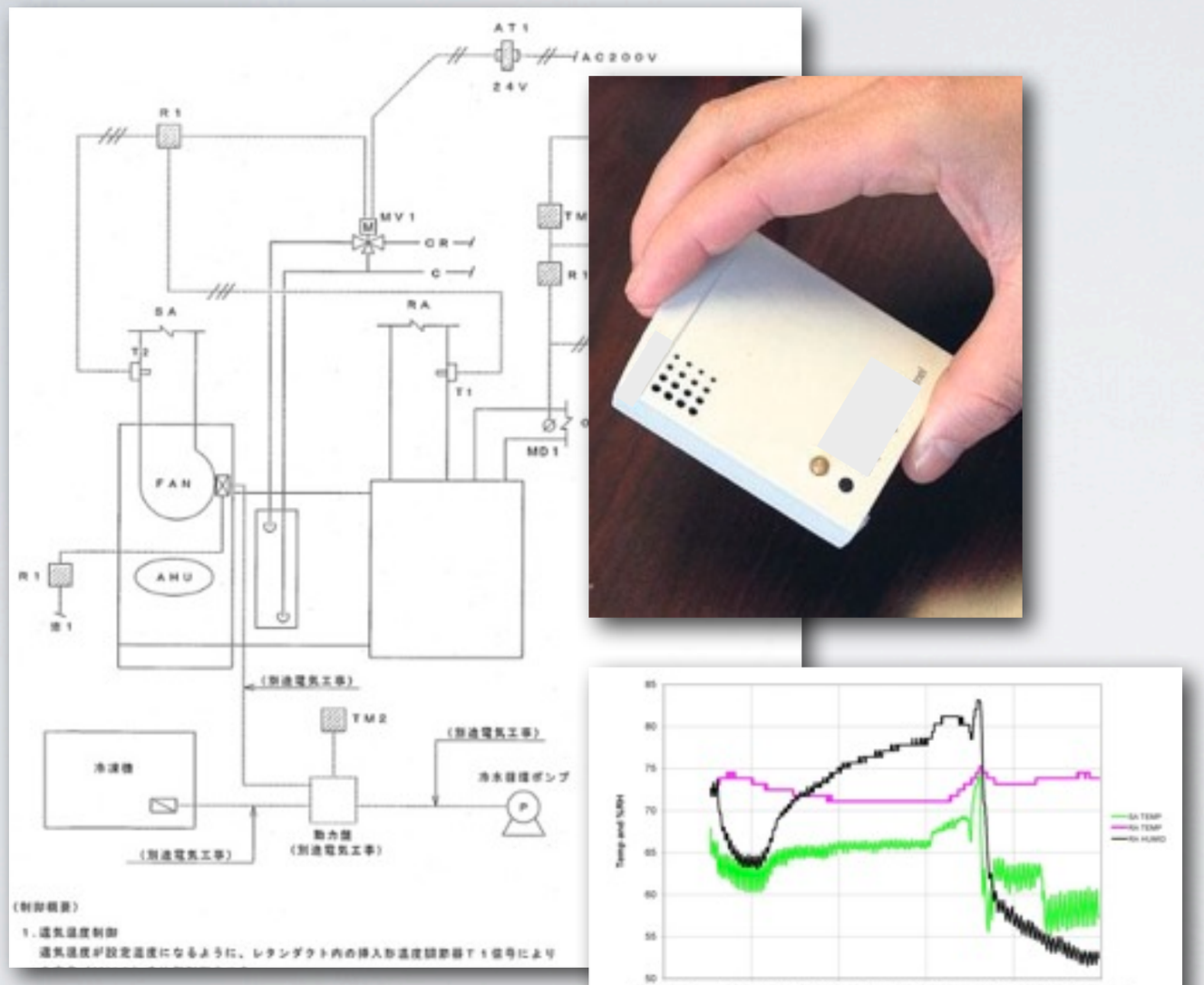







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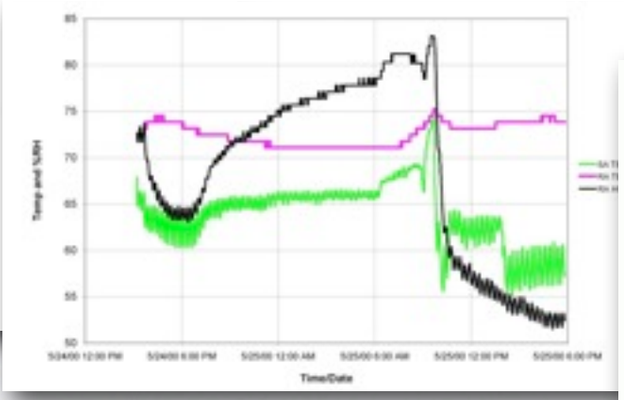
**Review diagrams, place dataloggers**

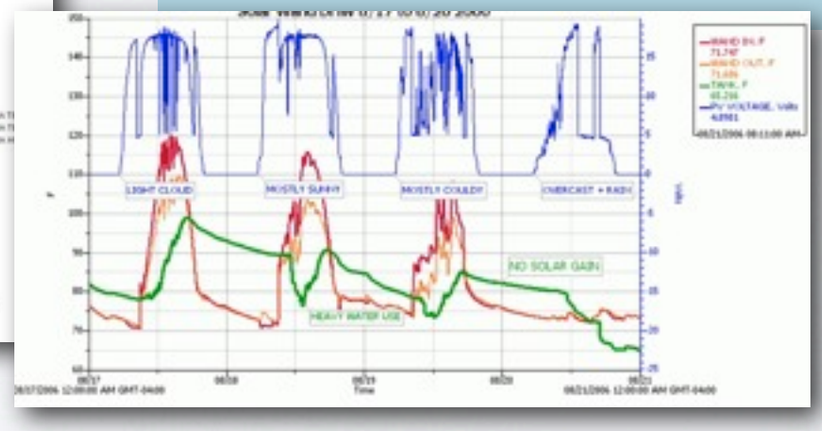
**..then compare to the real world**

# Measuring Dehumidification OVER TIME - Controls






Dehumidification

Humidity removal

Dry air flow

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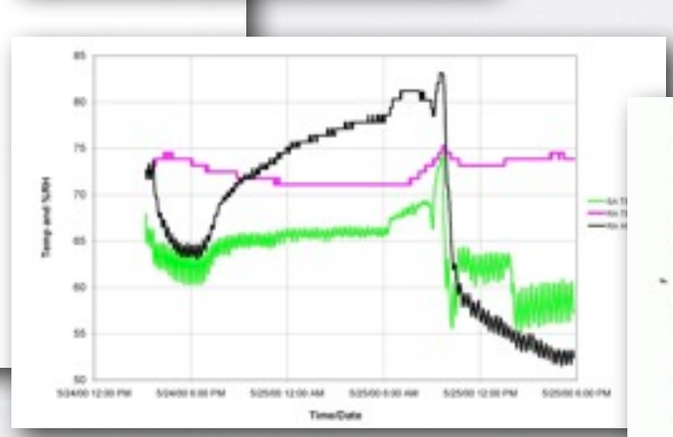


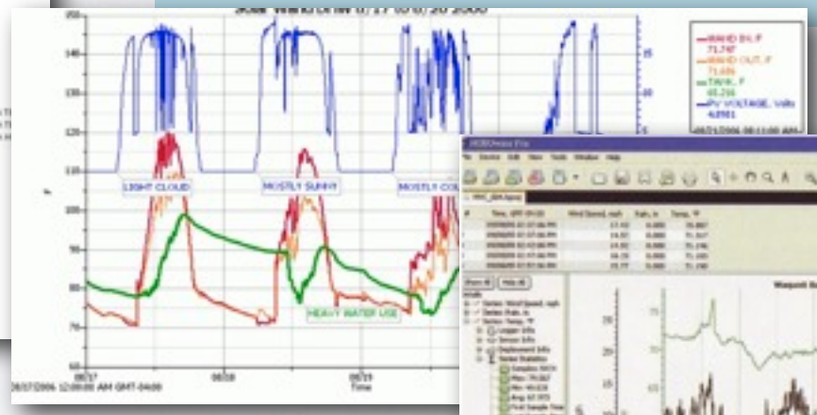


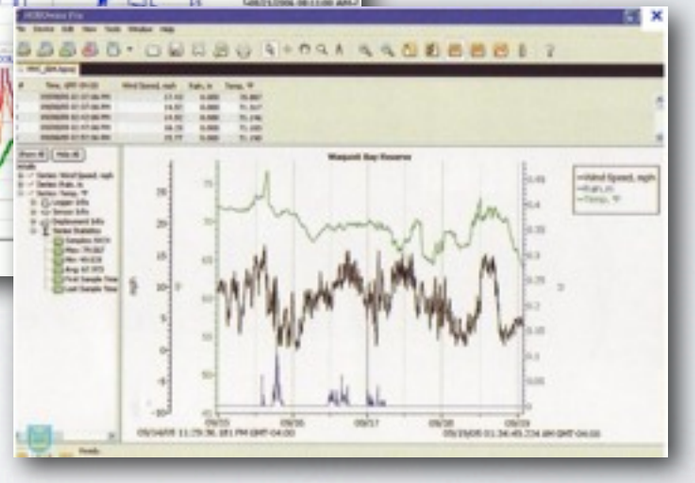

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# Logical sequence - Summary

1. Listen and understand the problems
2. Look at drawings, then walk though and understand the building
3. Look at drawings, then walk though and understand the HVAC system
4. Measure the key variables
   a. The loads
   b. The dehumidification
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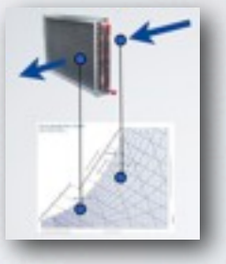

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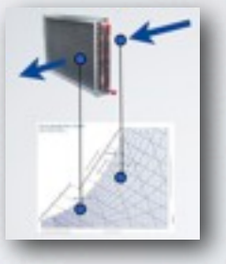

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# Community Clinic - Malaysia



# Problems at the clinic

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- Bad publicity forced closure and mold remediation in 2008
- Engineering firm had contract to remediate mold and re-adjust HVAC yet again. Wanted to get to the root of the ongoing problems and solve them... permanently.

# Air infiltration + humidity load

**Average Dew Point**

| Year | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73.4°F | 71.6°F | 71.6°F | 73.4°F | 73.4°F | 73.4°F | 73.4°F | 73.4°F | 71.6°F | 73.4°F | 73.4°F | 73.4°F | 71.6°F |



# Air infiltration + humidity load

55˚F dew point

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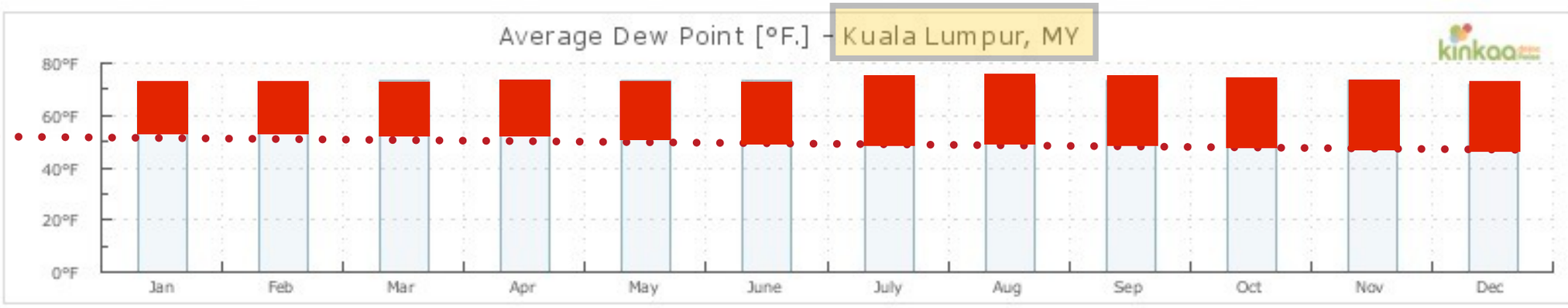

# Limited Hours of HVAC Operation



# Building floor plans



# Indoor dew point = 12.0˚C (54˚F) - Excellent!



# South-facing lobby, 1st floor - No mold



# South-facing lobby, 1st floor - No mold



# Examination rooms - Big problems with mold



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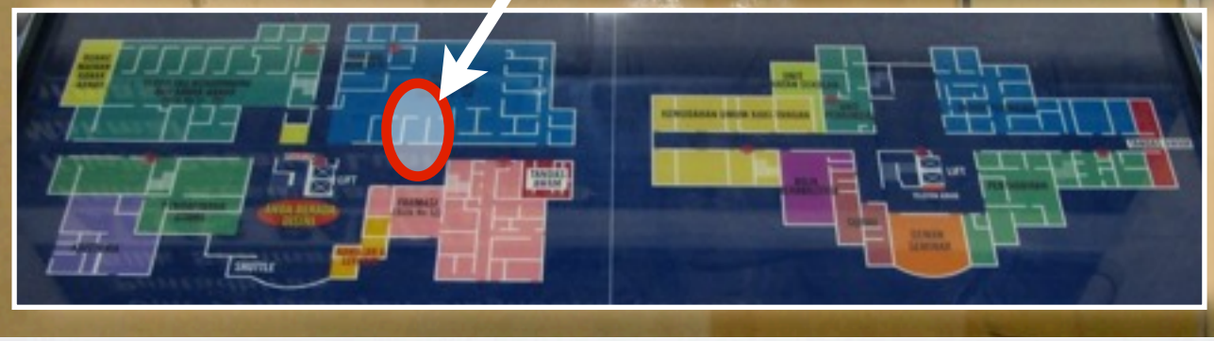

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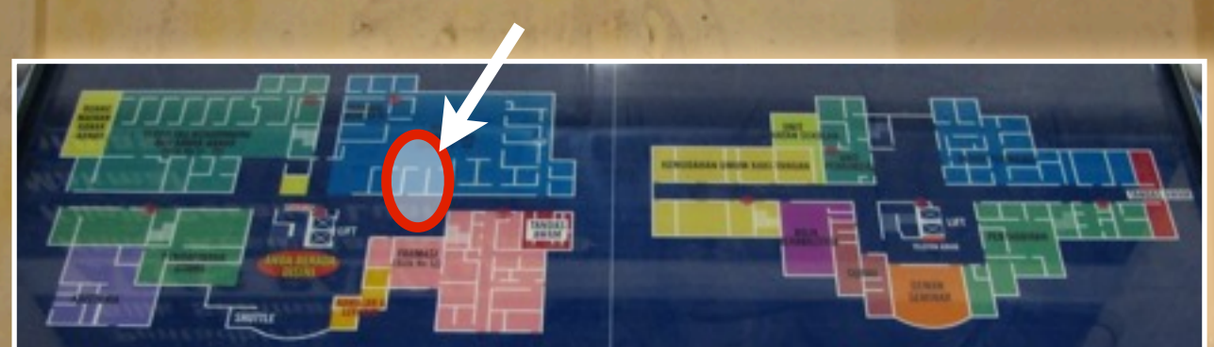

# Looking inwards... from the west wall



# Looking inwards... from the west wall



# 2nd floor - Looking outwards,  toward west wall



# 2nd floor - Looking outwards,  toward west wall



# 1st floor - East wing corridor



# 1st floor - East wing corridor



# Water-soaked insulation collapsed the ceiling



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# DAYLIGHT above the 1st floor ceiling....??!!



# DAYLIGHT above the 1st floor ceiling....??!!



# South elevation



# Note the gutter dimensions...



# Roof-wall connection



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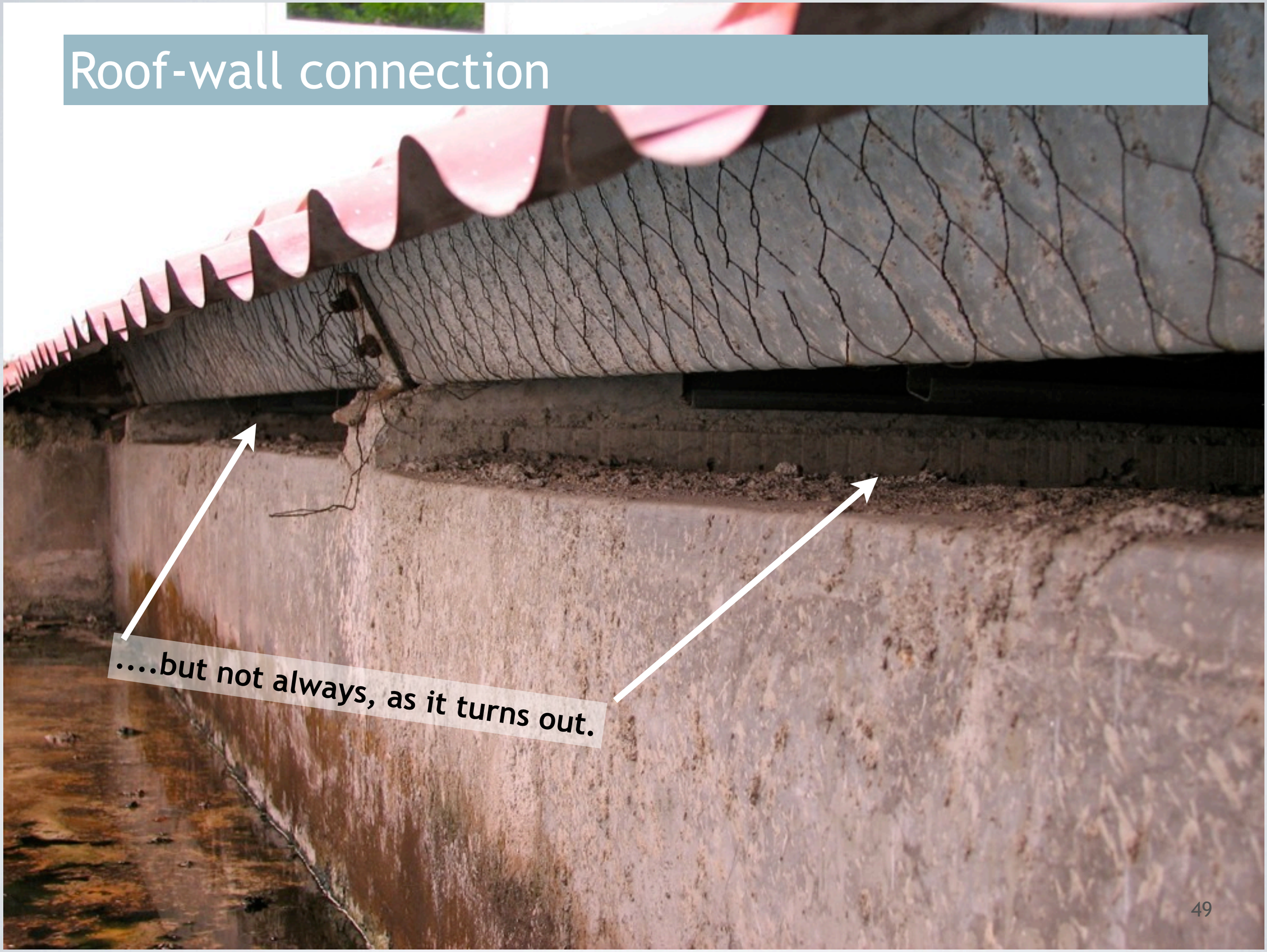

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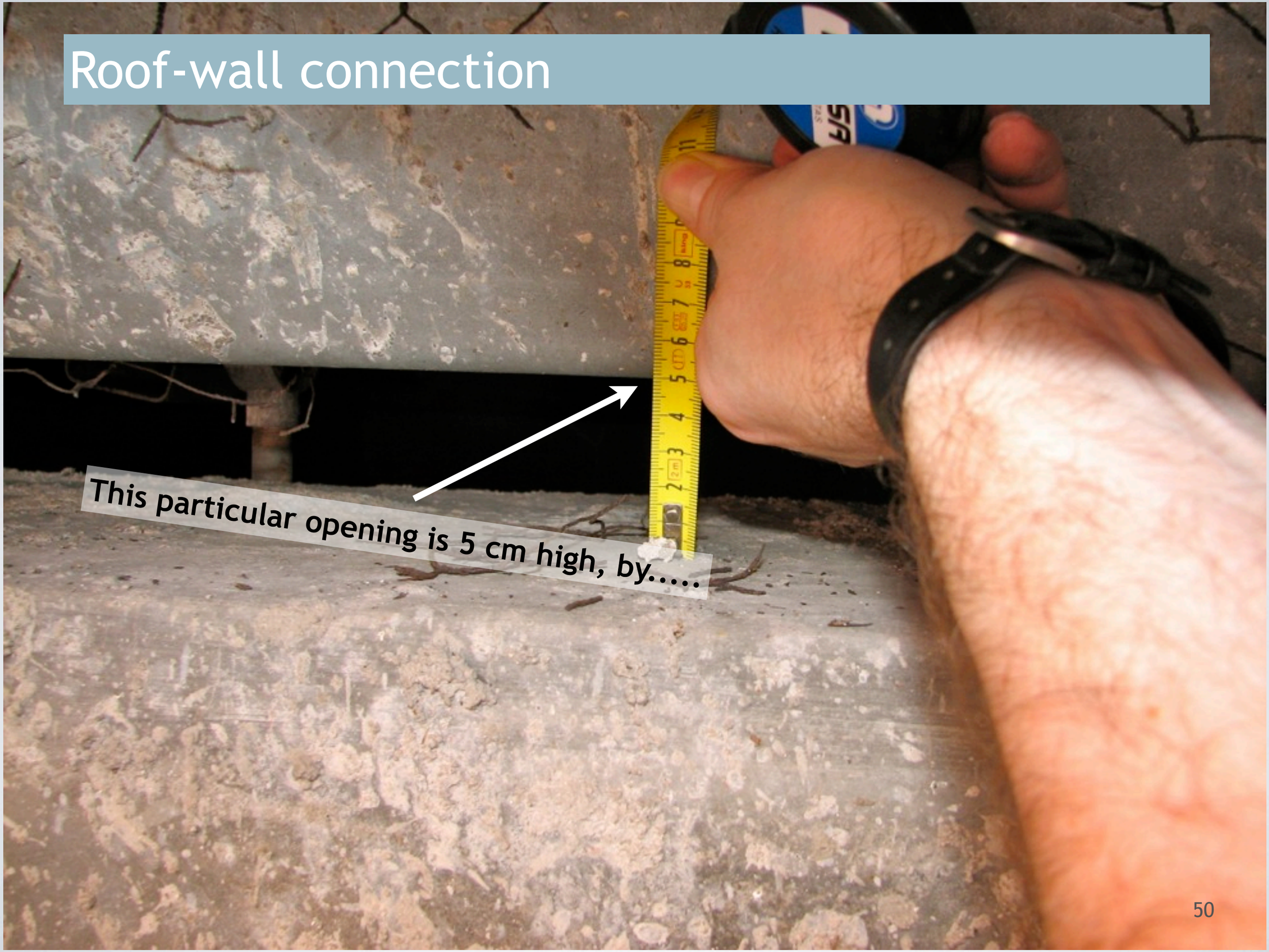

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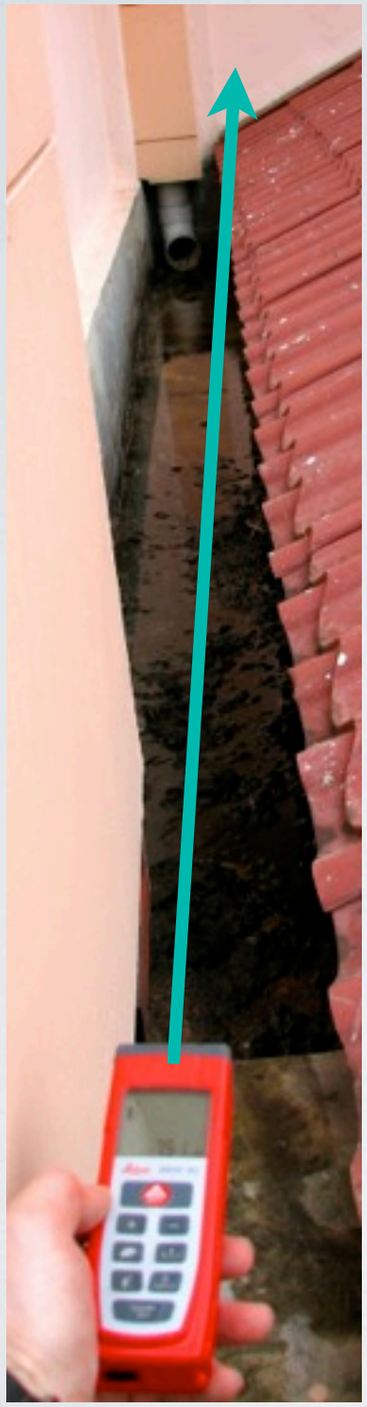



**by... 7.5 meters long (15 ft.)**

**So this particular gap measures 2.5 ft2 open area**

# Roof-wall connection



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# Roof-wall connection



# Installers don’t always pay attention to sealing up holes they make...



# Installers don’t always pay attention to sealing up holes they make...



# Excellent mechanical room - Entire 3rd floor



# Ventilation air enters through mechanical room



# ... but duct chases are not all sealed, so outdoor air falls into the building after entering though the mechanical room



# 54°F indoor dew point when systems are operating....



... rises to 66°F dew point only 20 minutes after systems turn off..



... rises to 66°F dew point only 20 minutes after systems turn off..

... which means the rh AT THE SURFACE is over 95%

... rises to 66°F dew point only 20 minutes after systems turn off..



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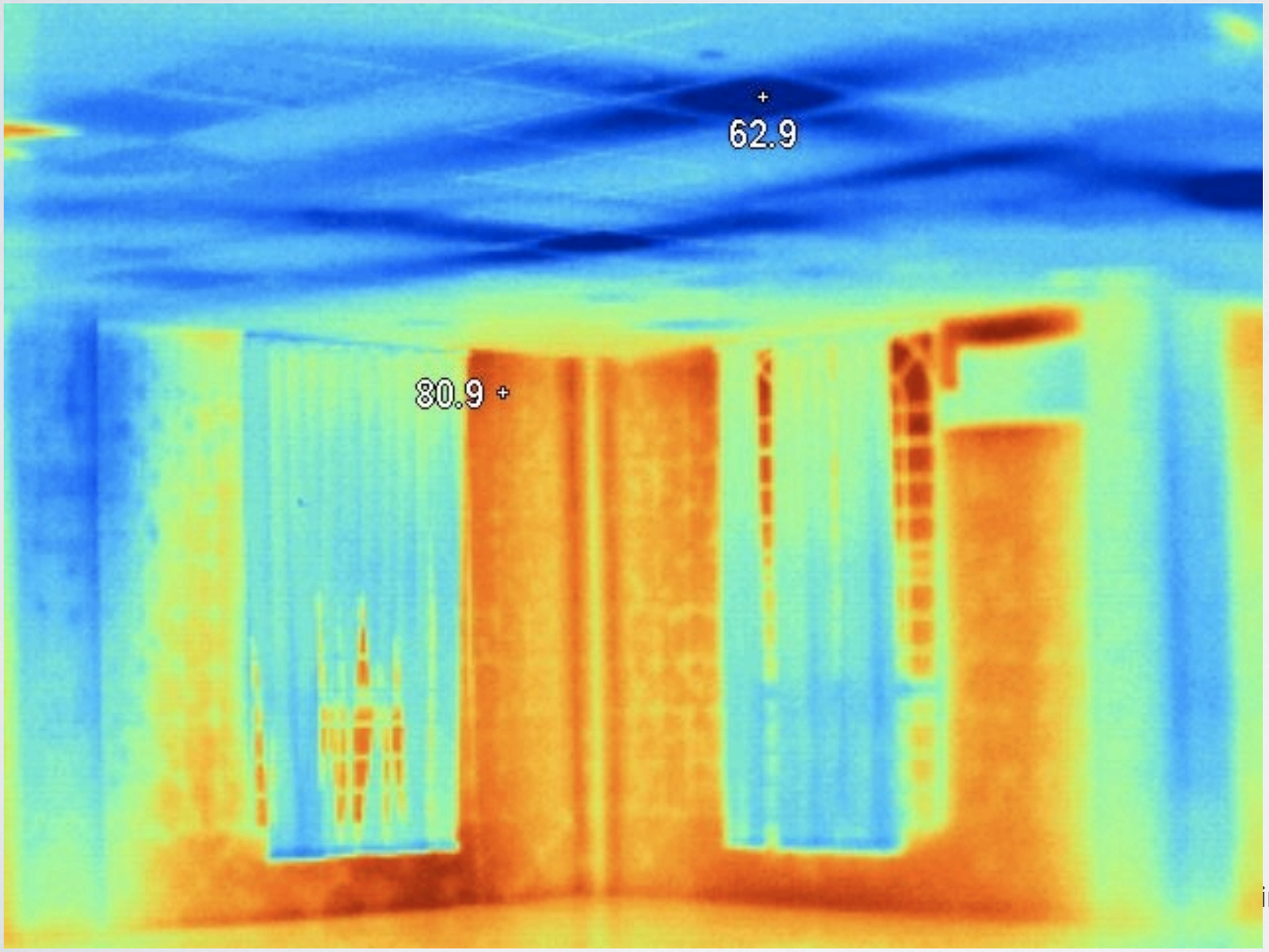
The mold grows because high dew point outdoor air easily falls into the building through the wide gaps and holes..

... while the AC system overchills the building under the mistaken assumption that more cooling = humidity control and mold avoidance

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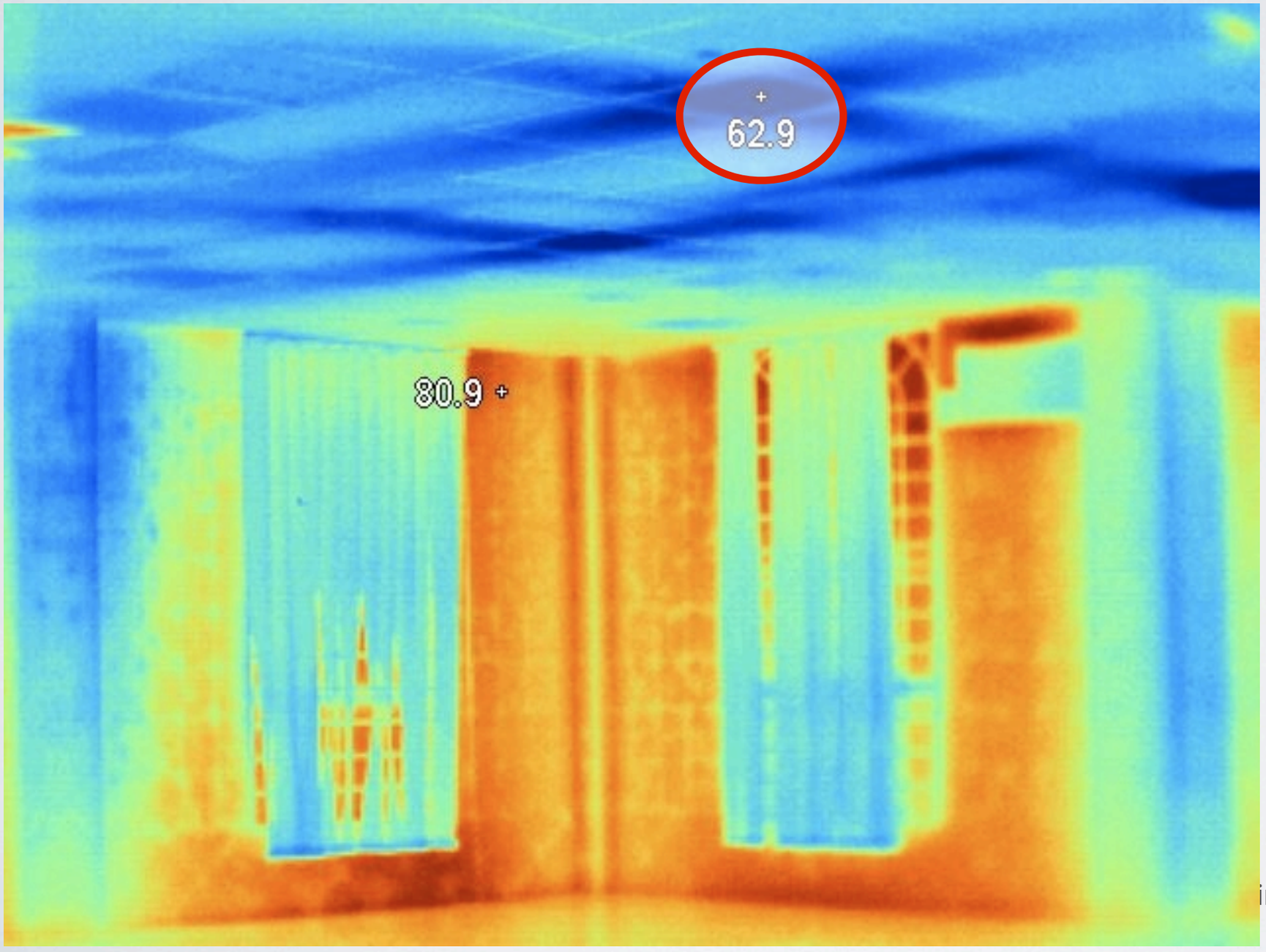


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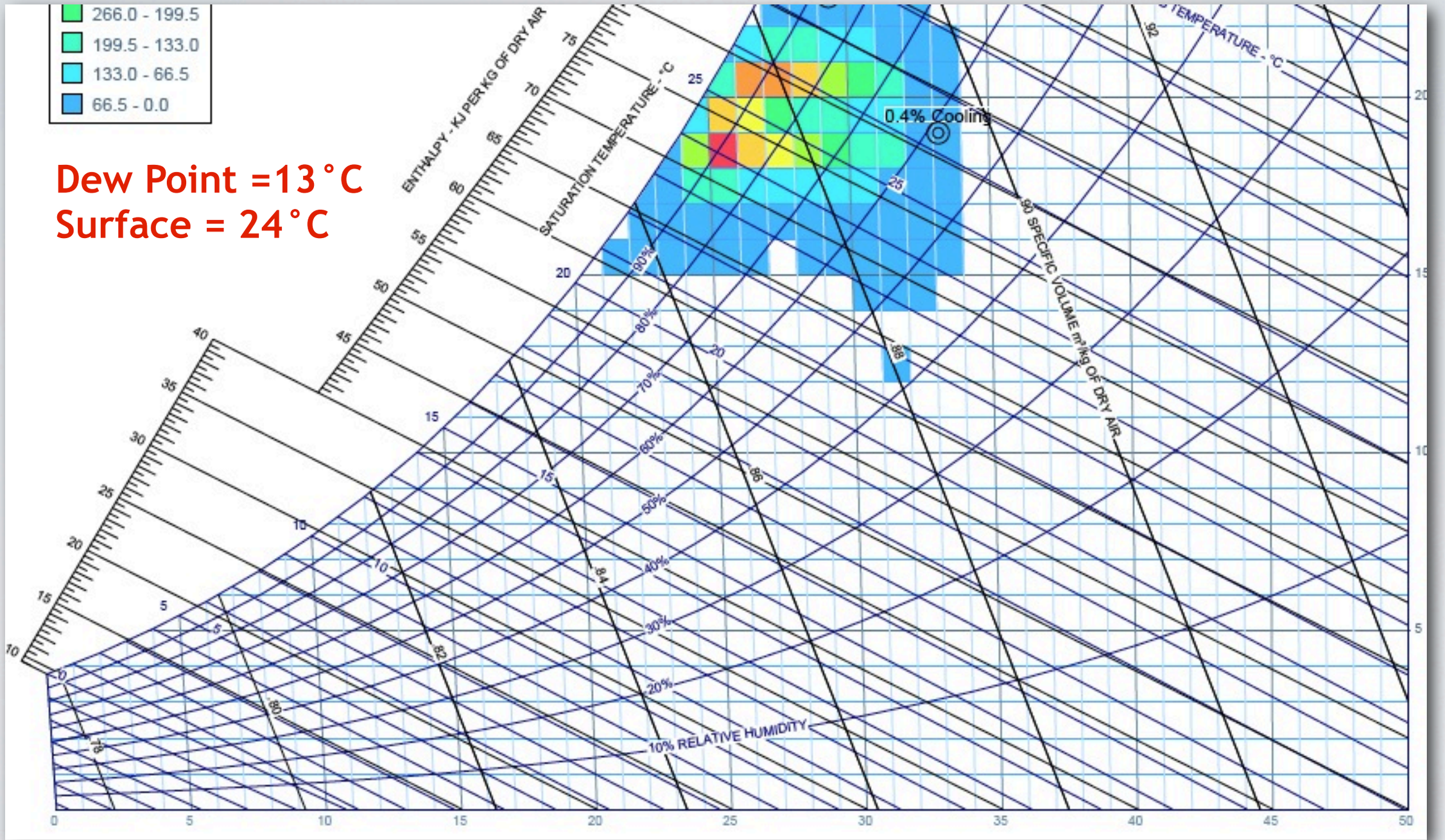
# Exercise - Finding the RH AT THE SURFACE, using a psychrometric chart



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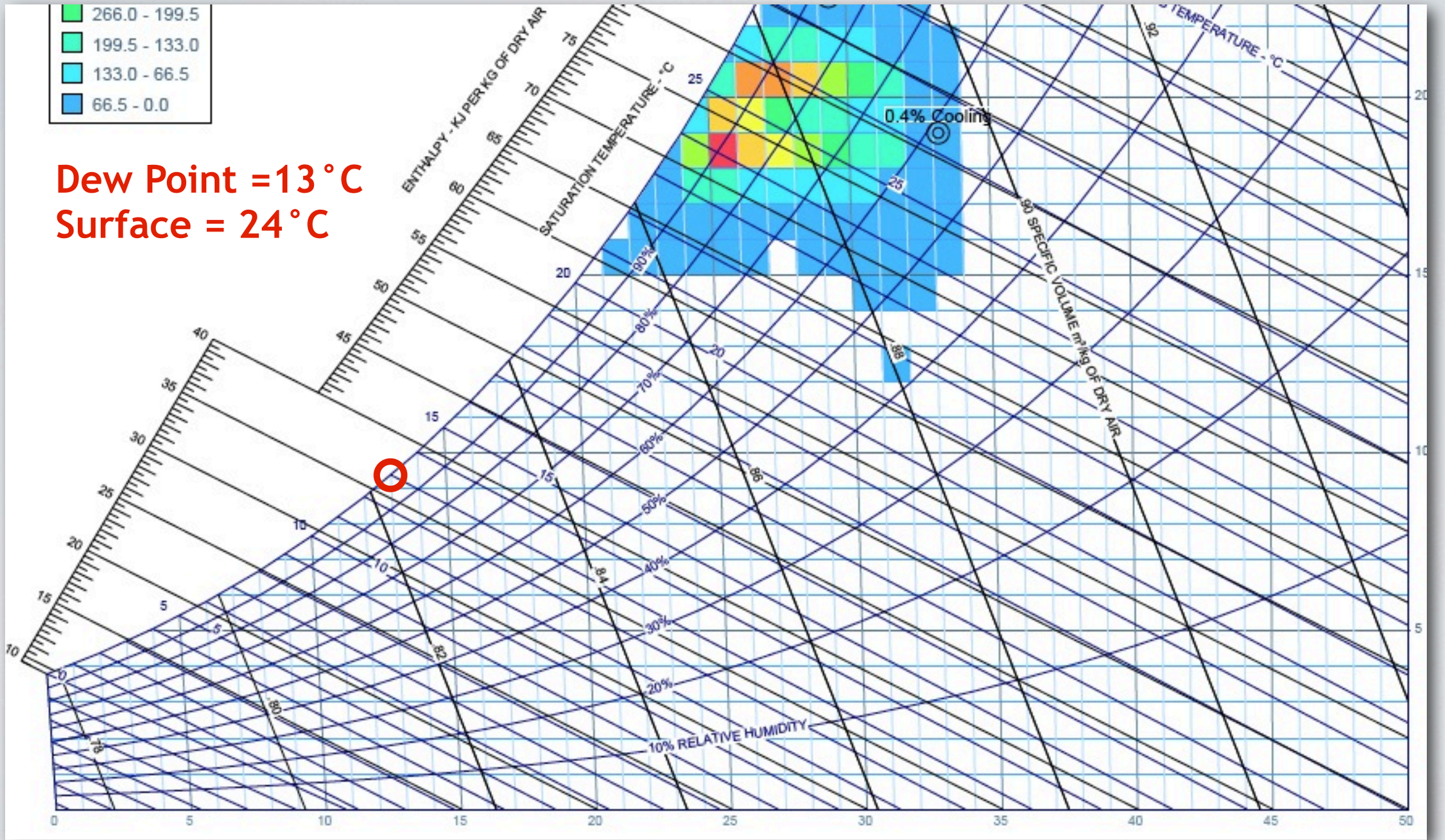

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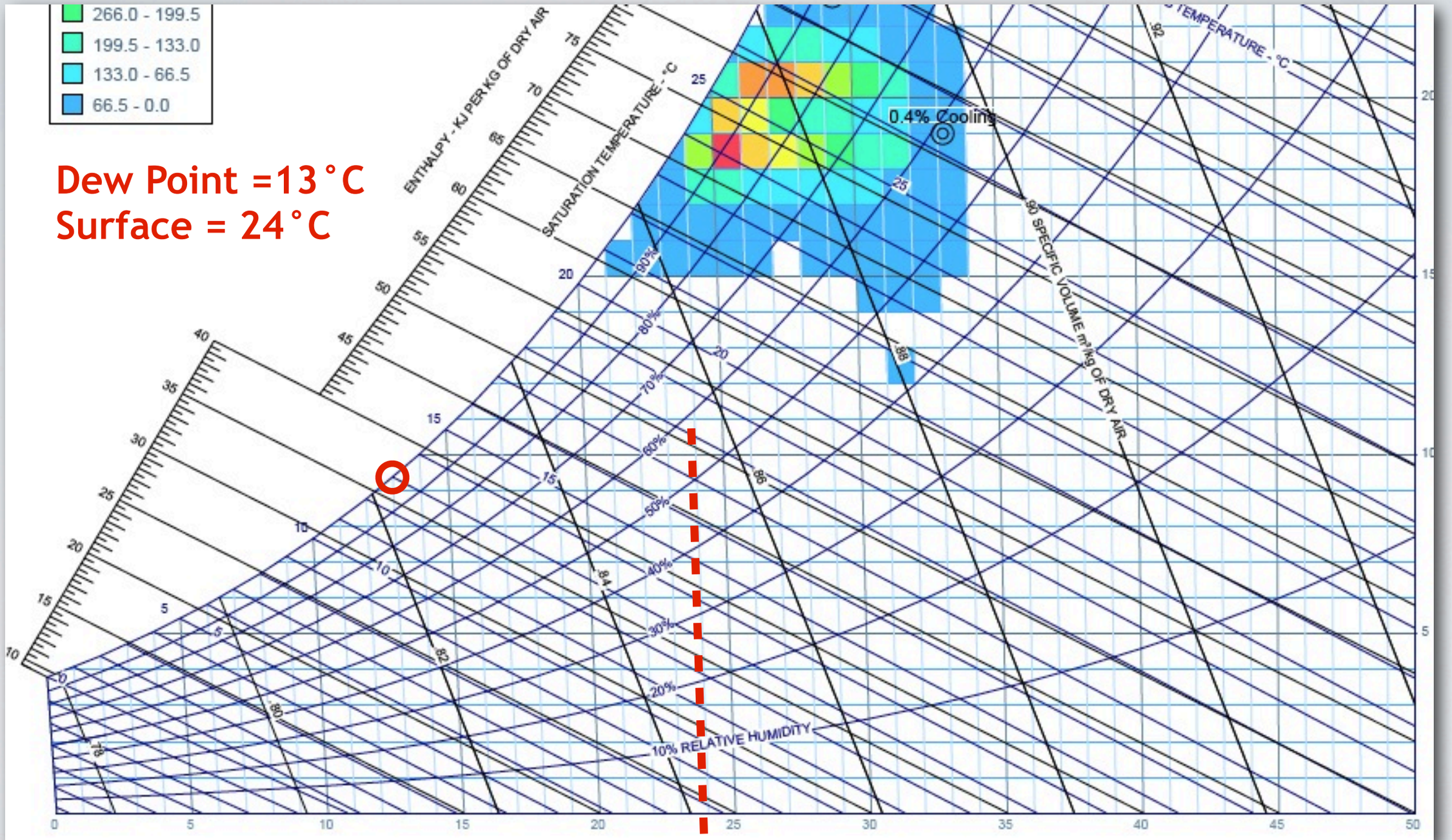

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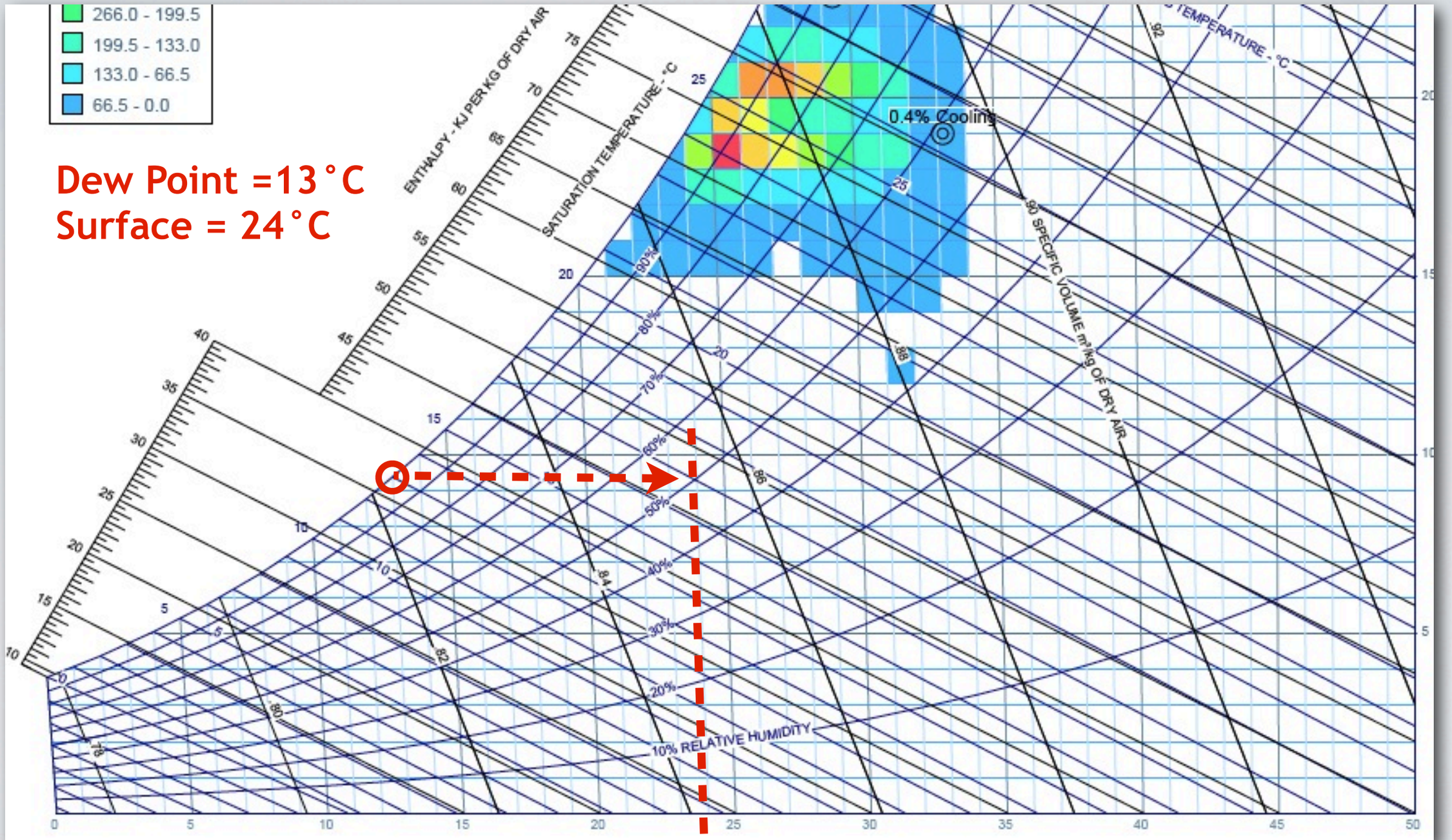

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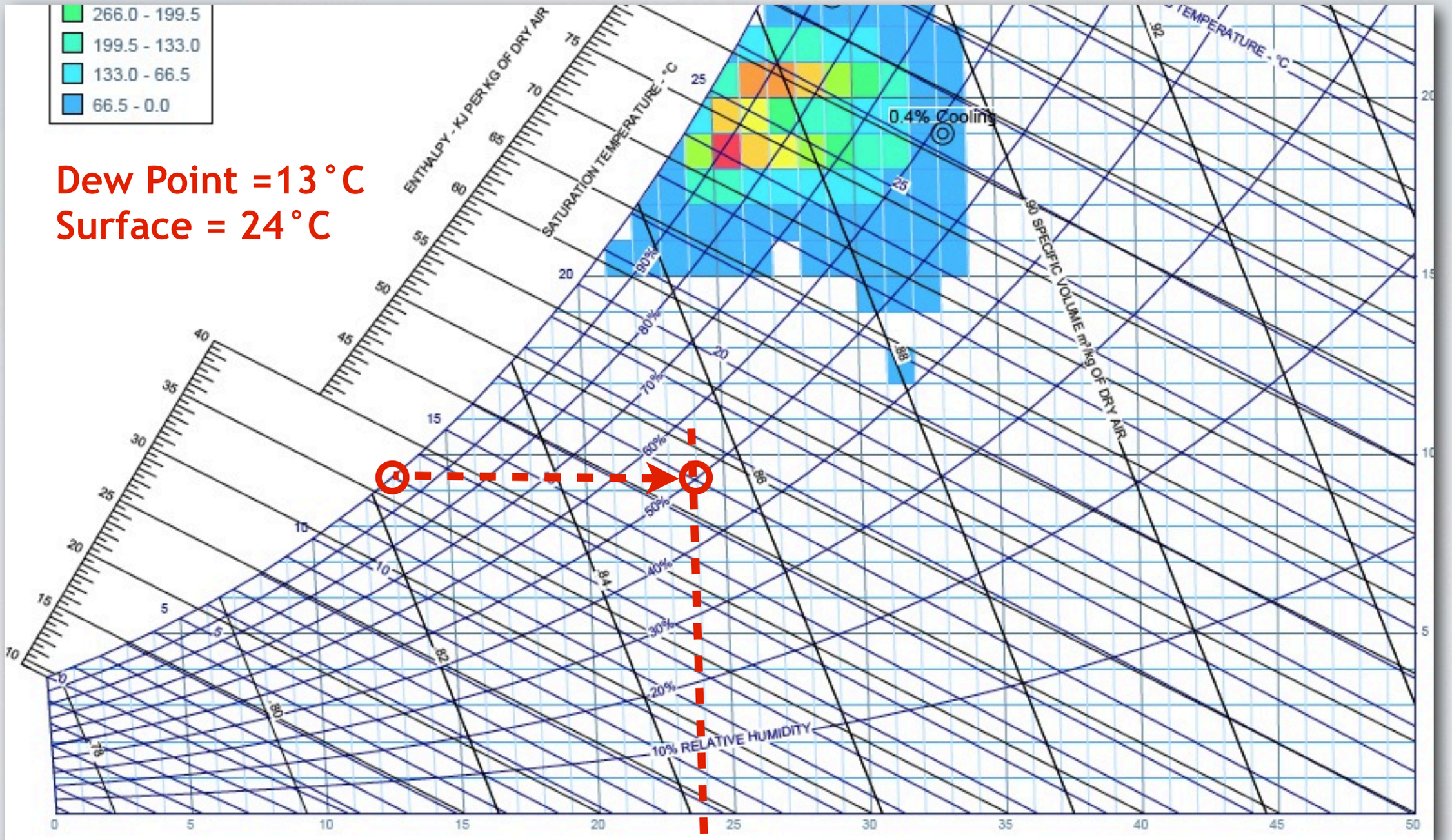

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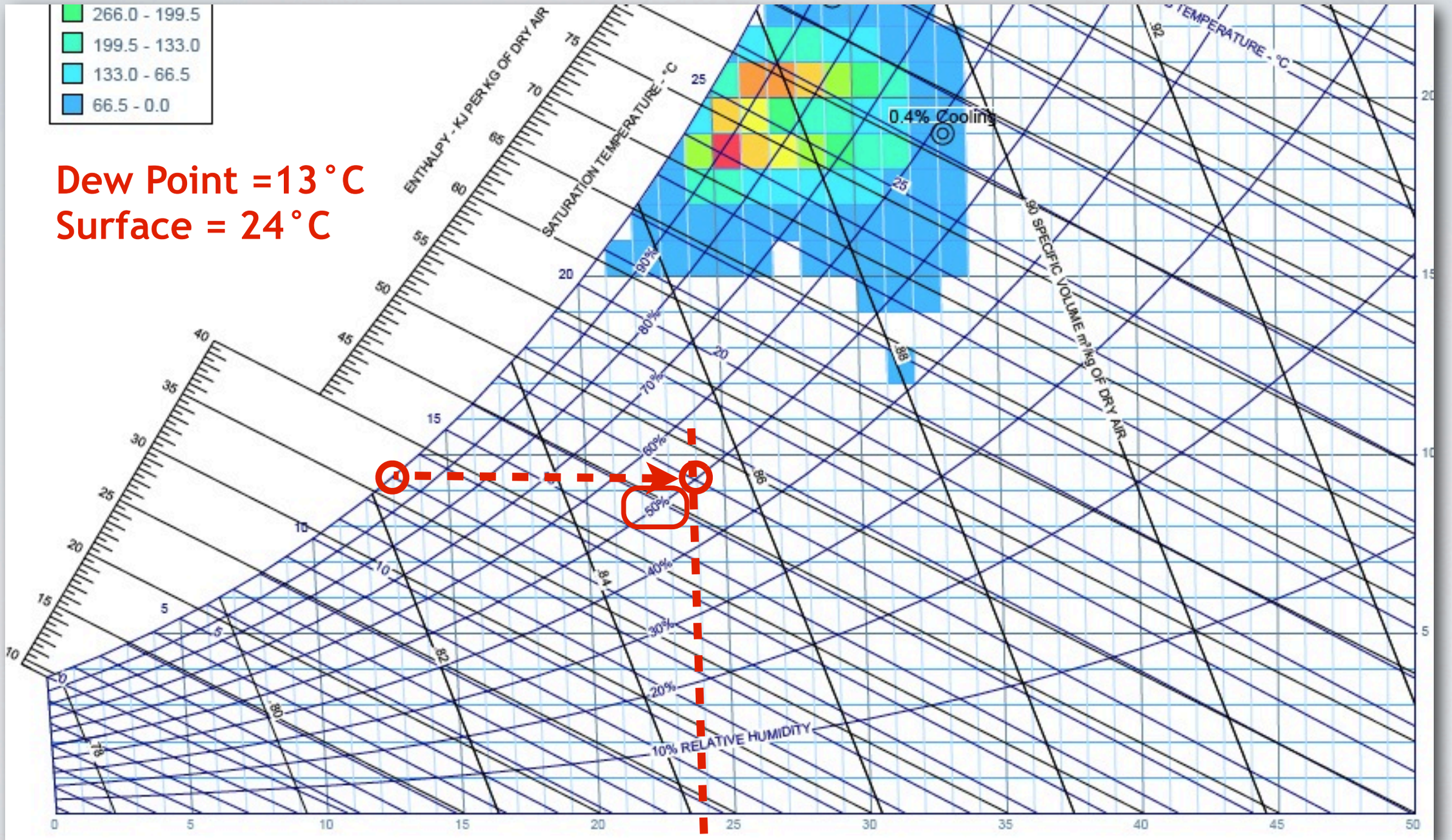

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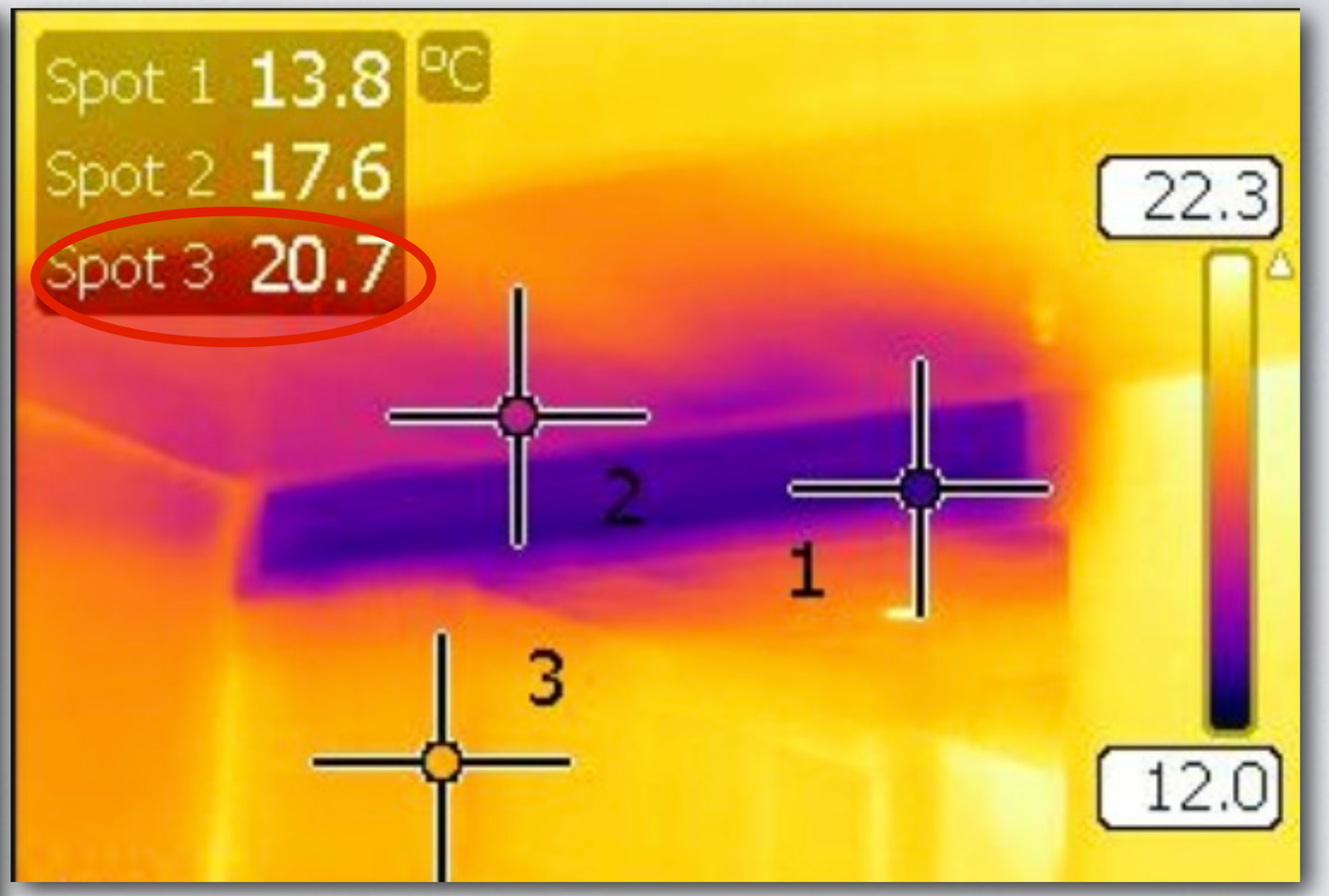

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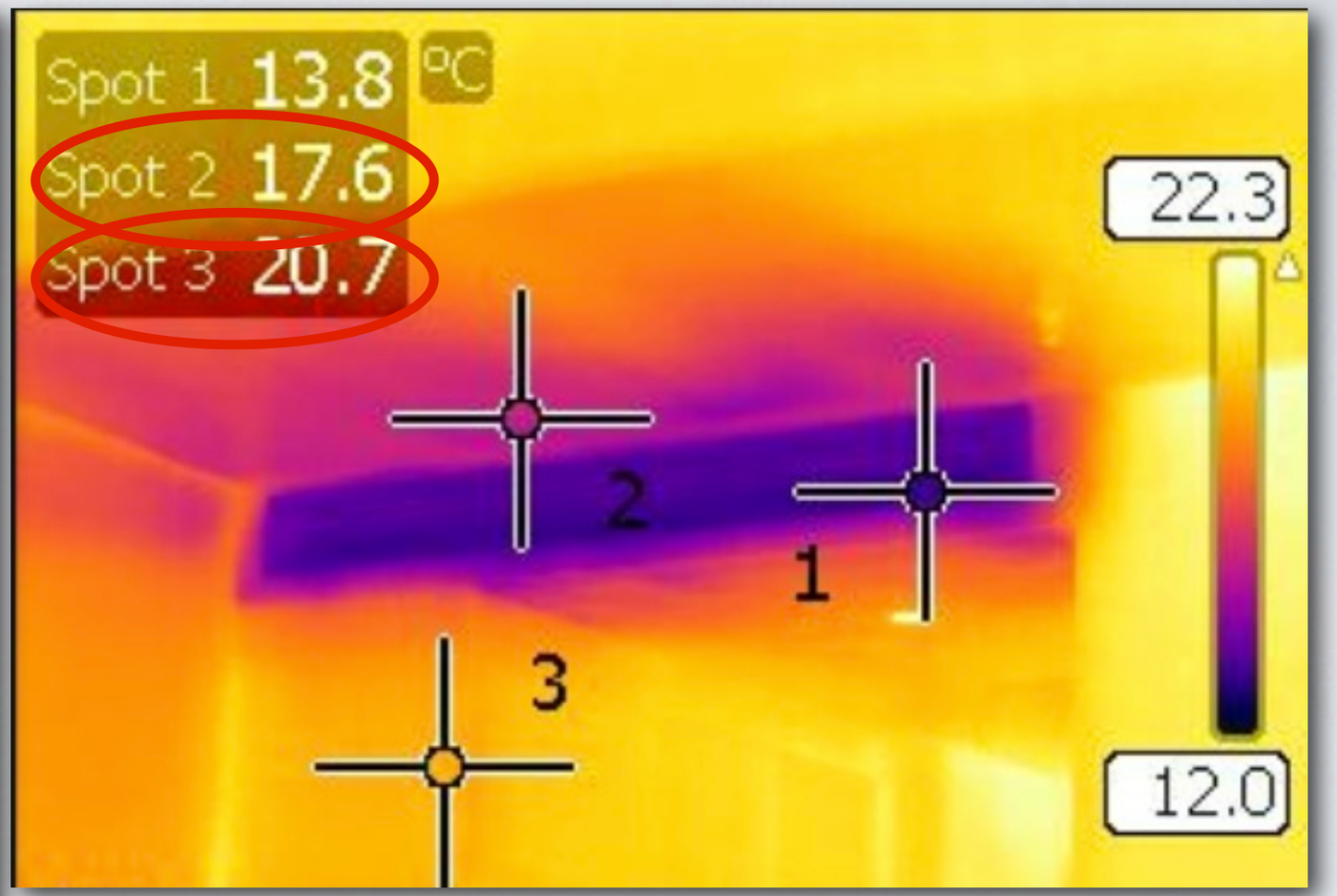

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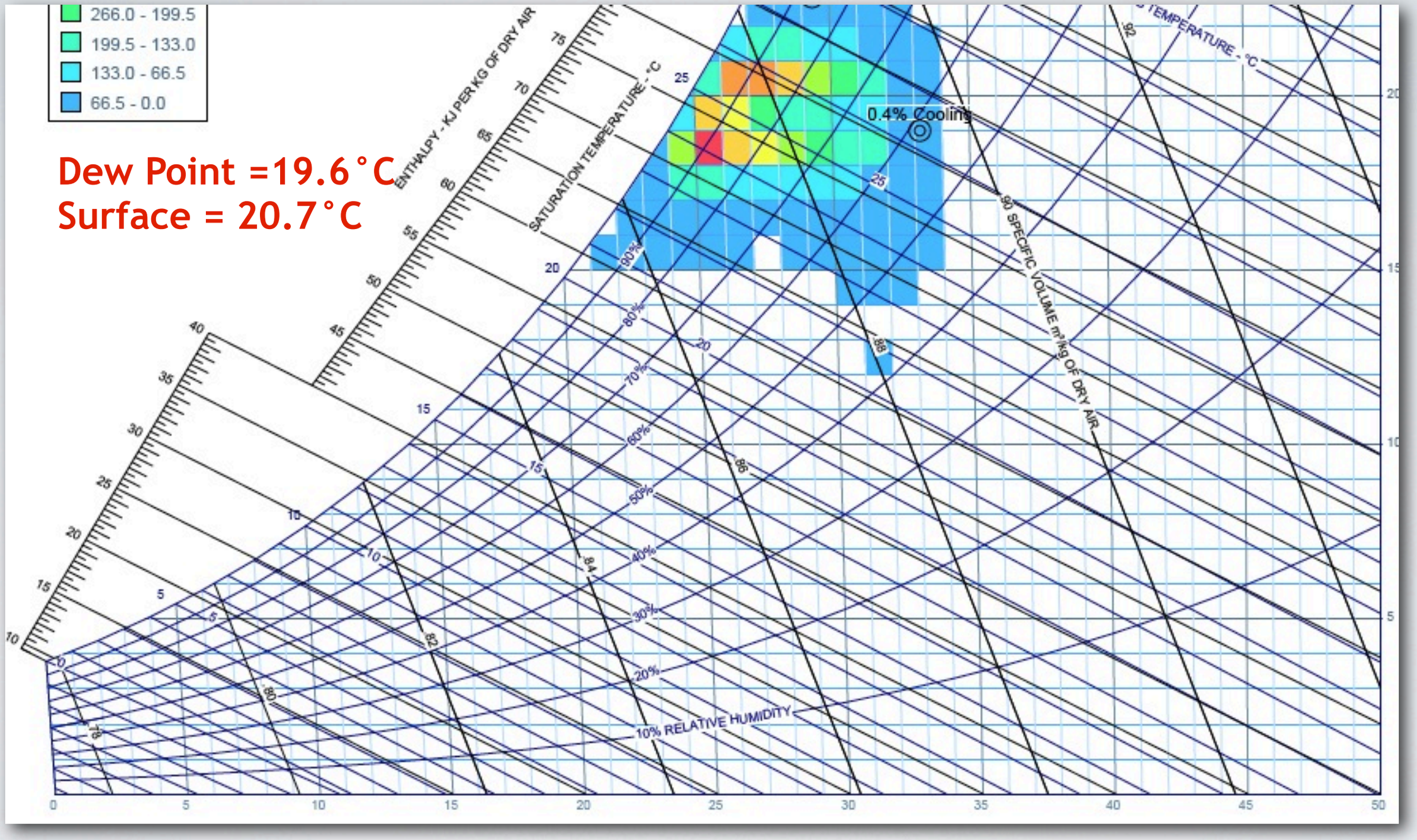

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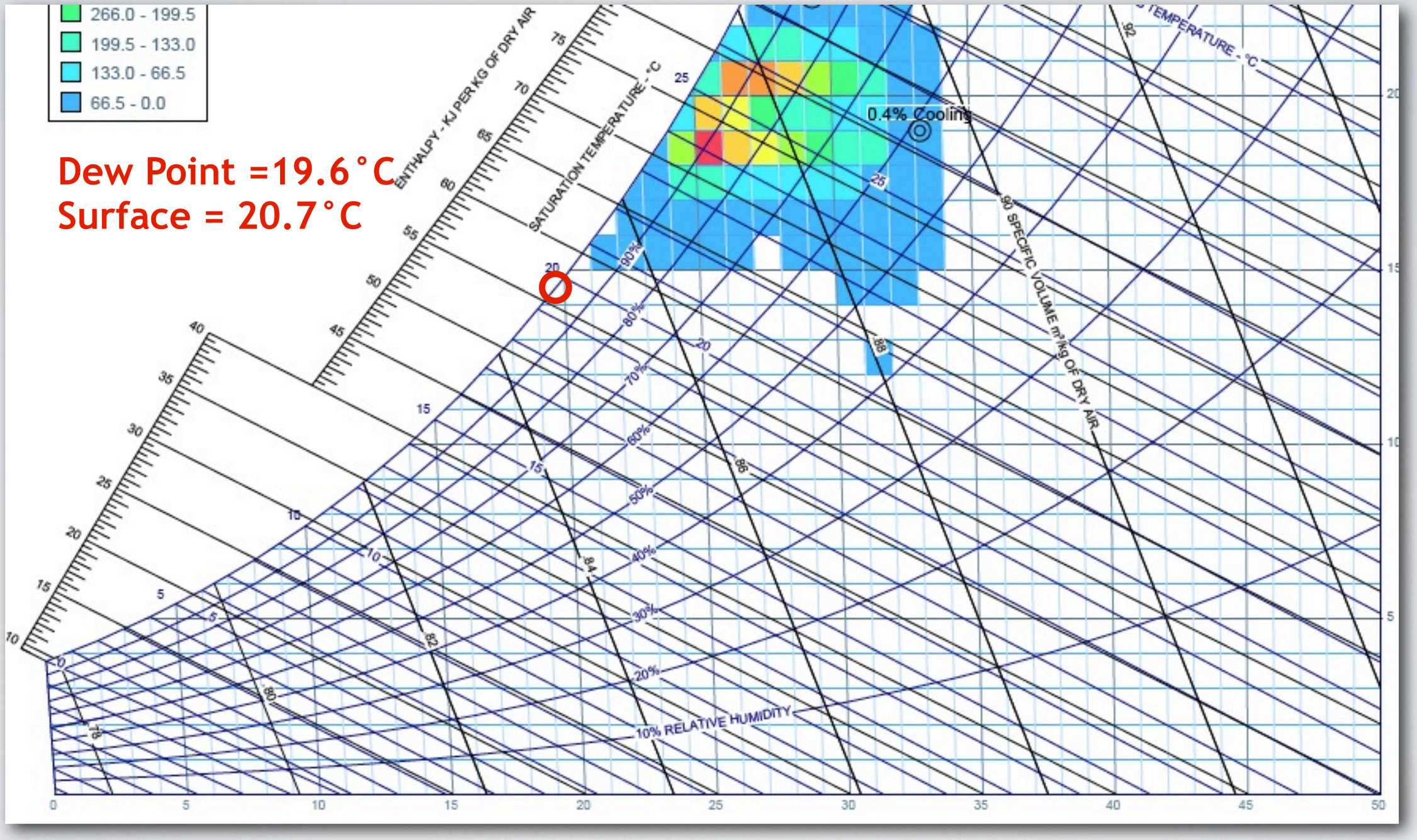

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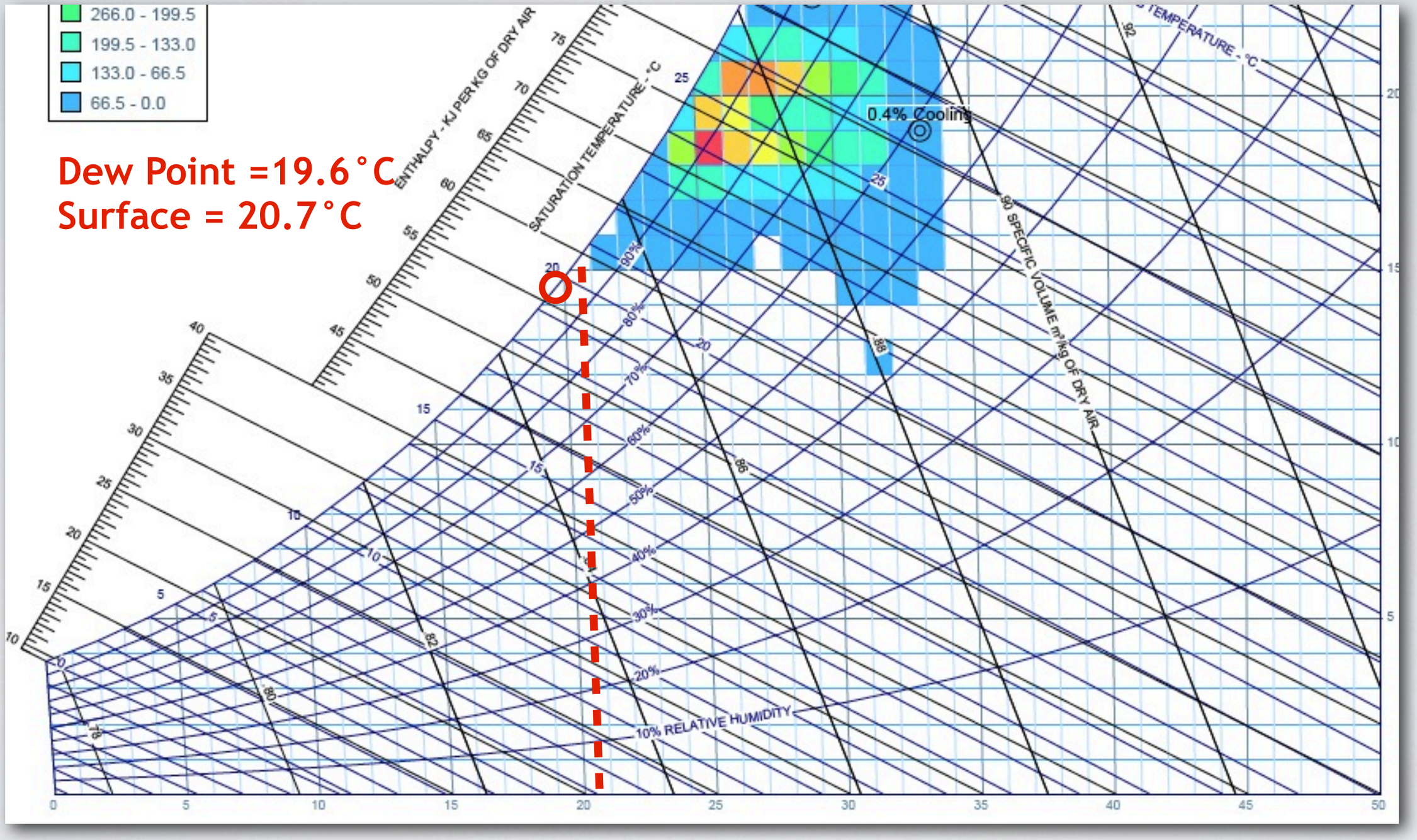

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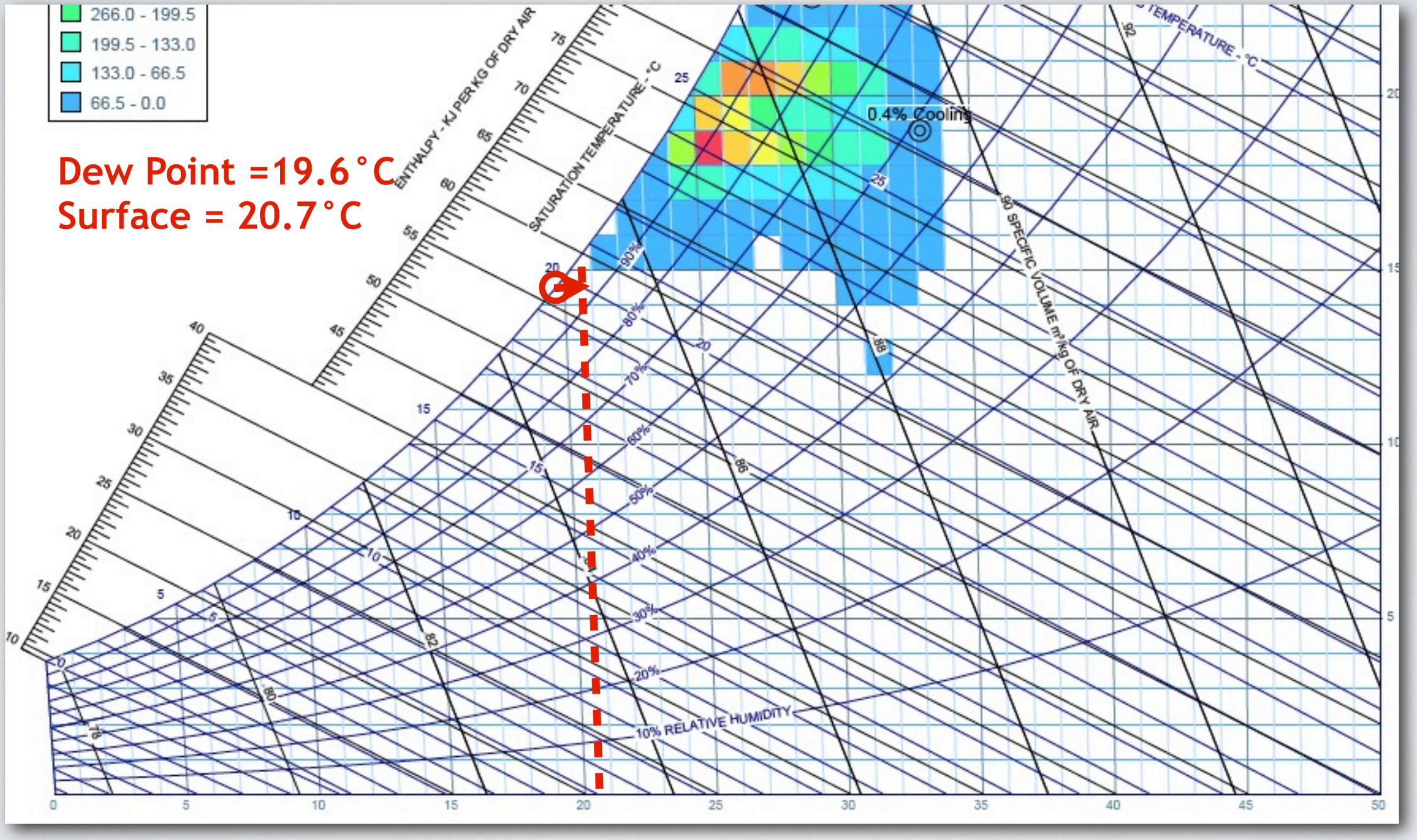

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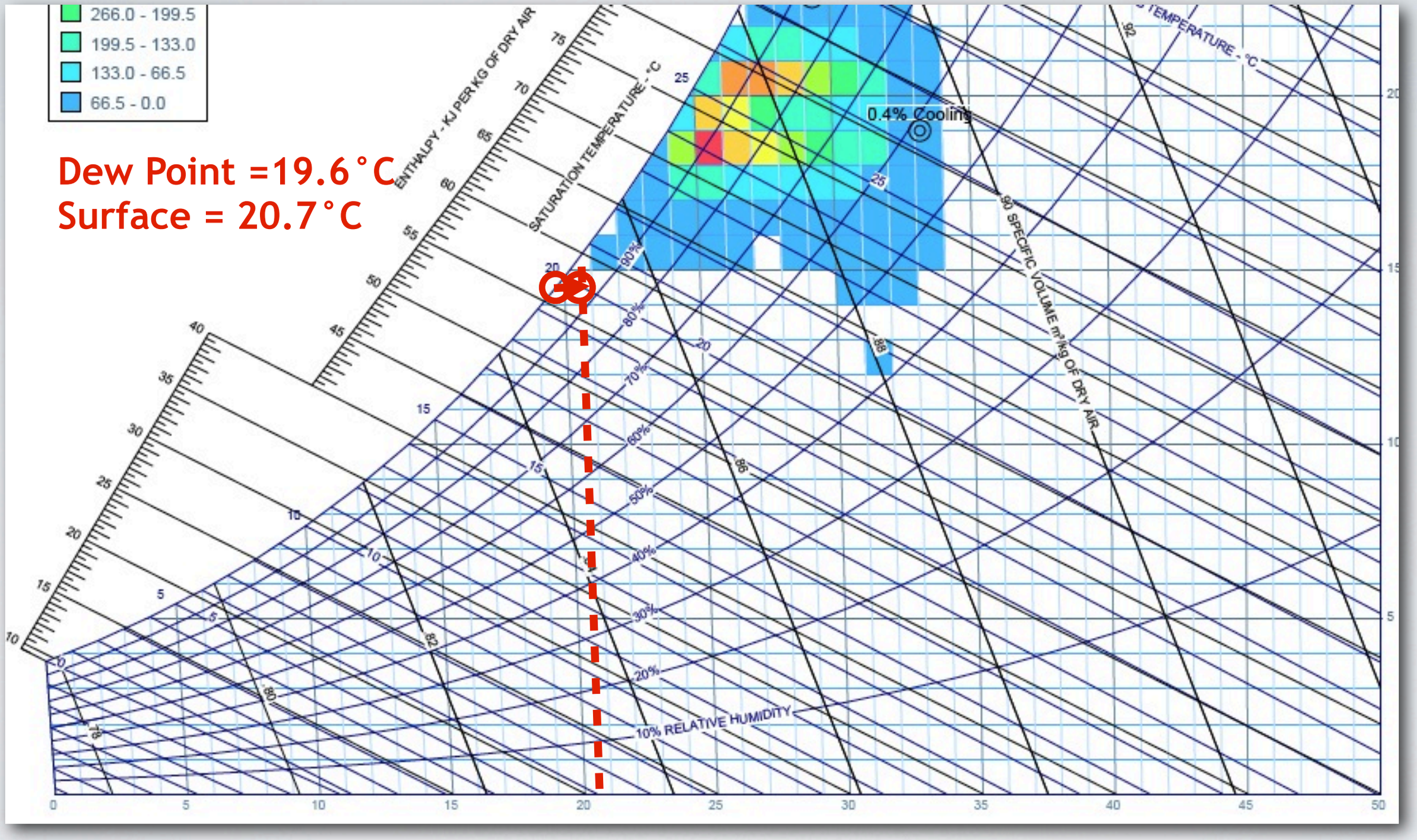

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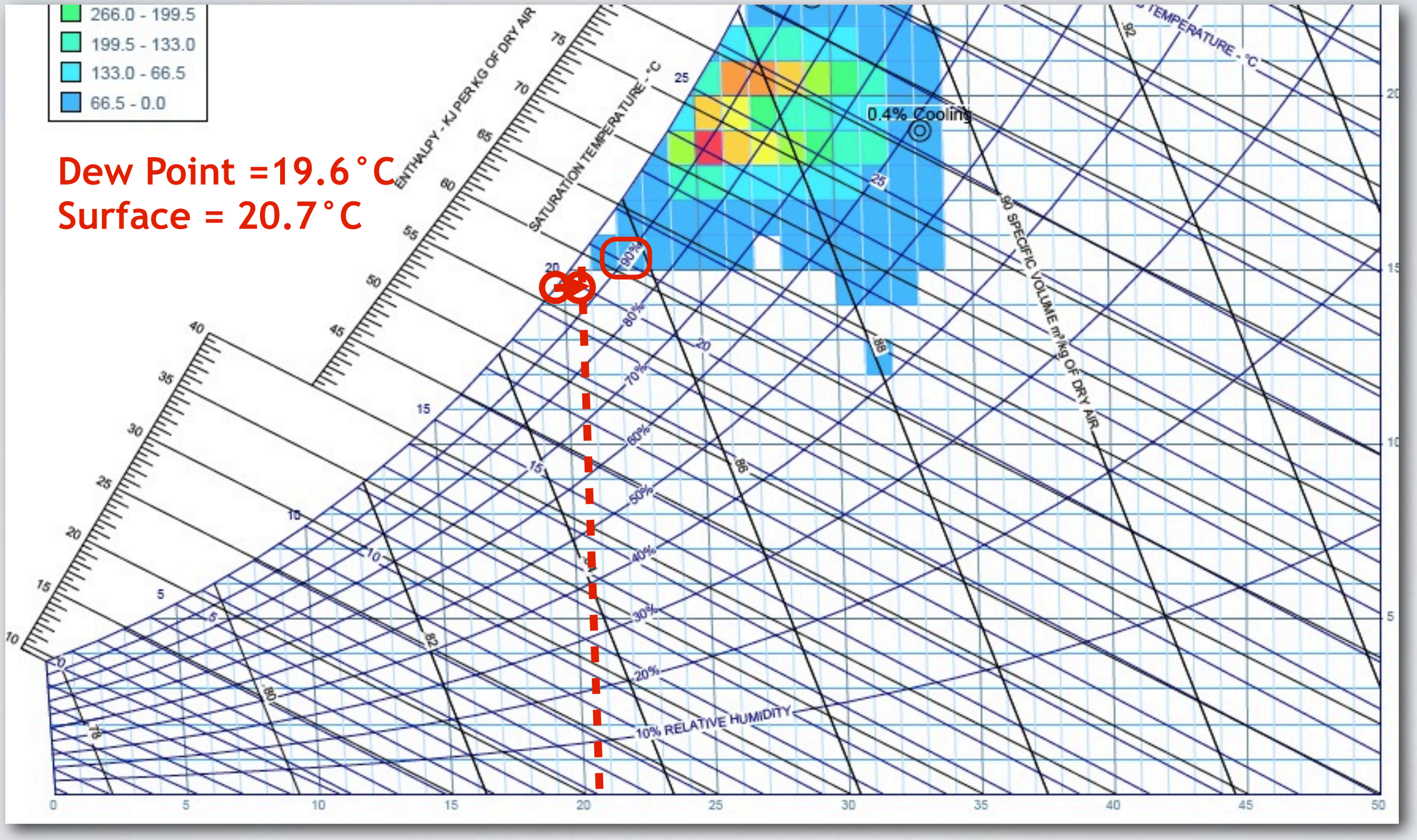

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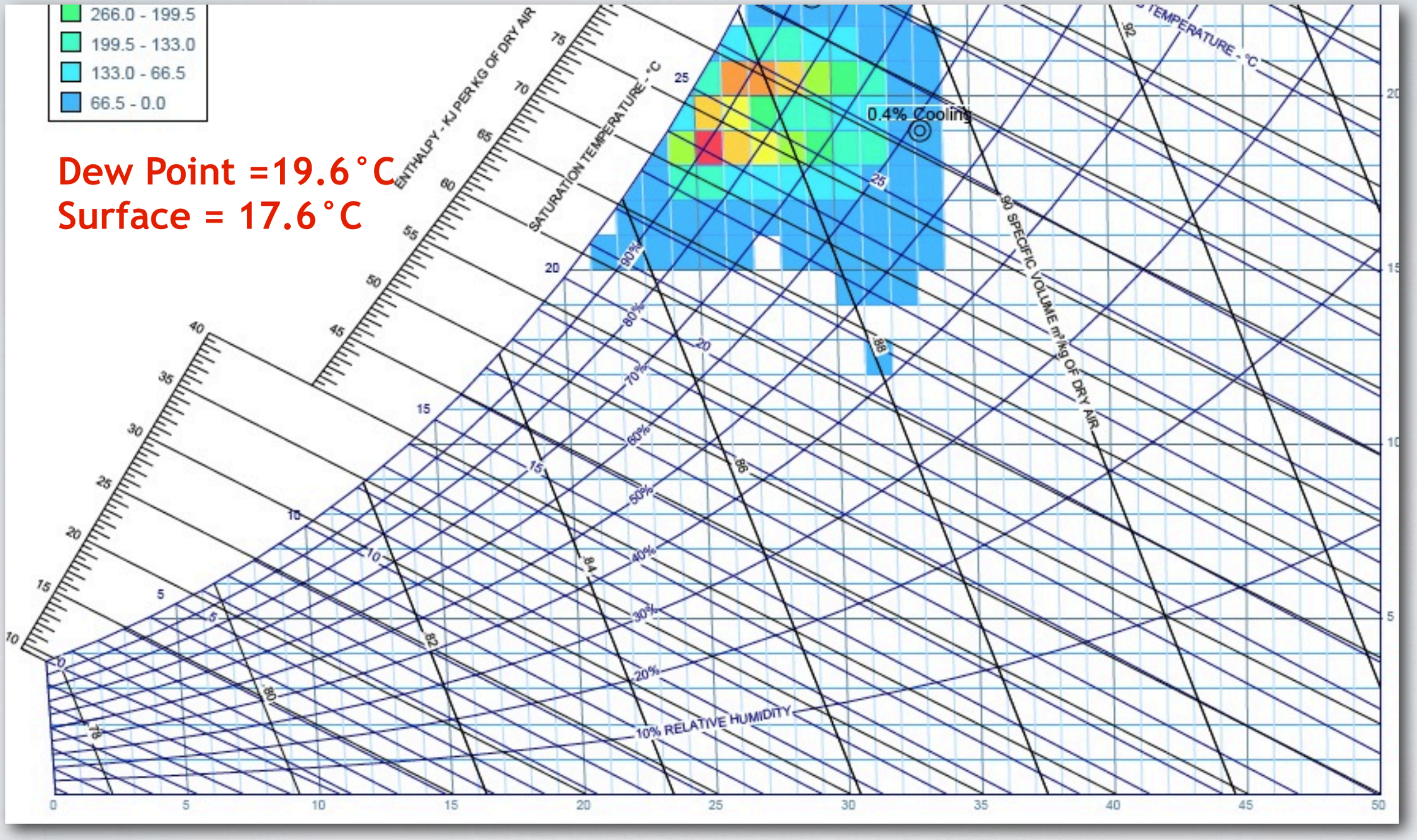

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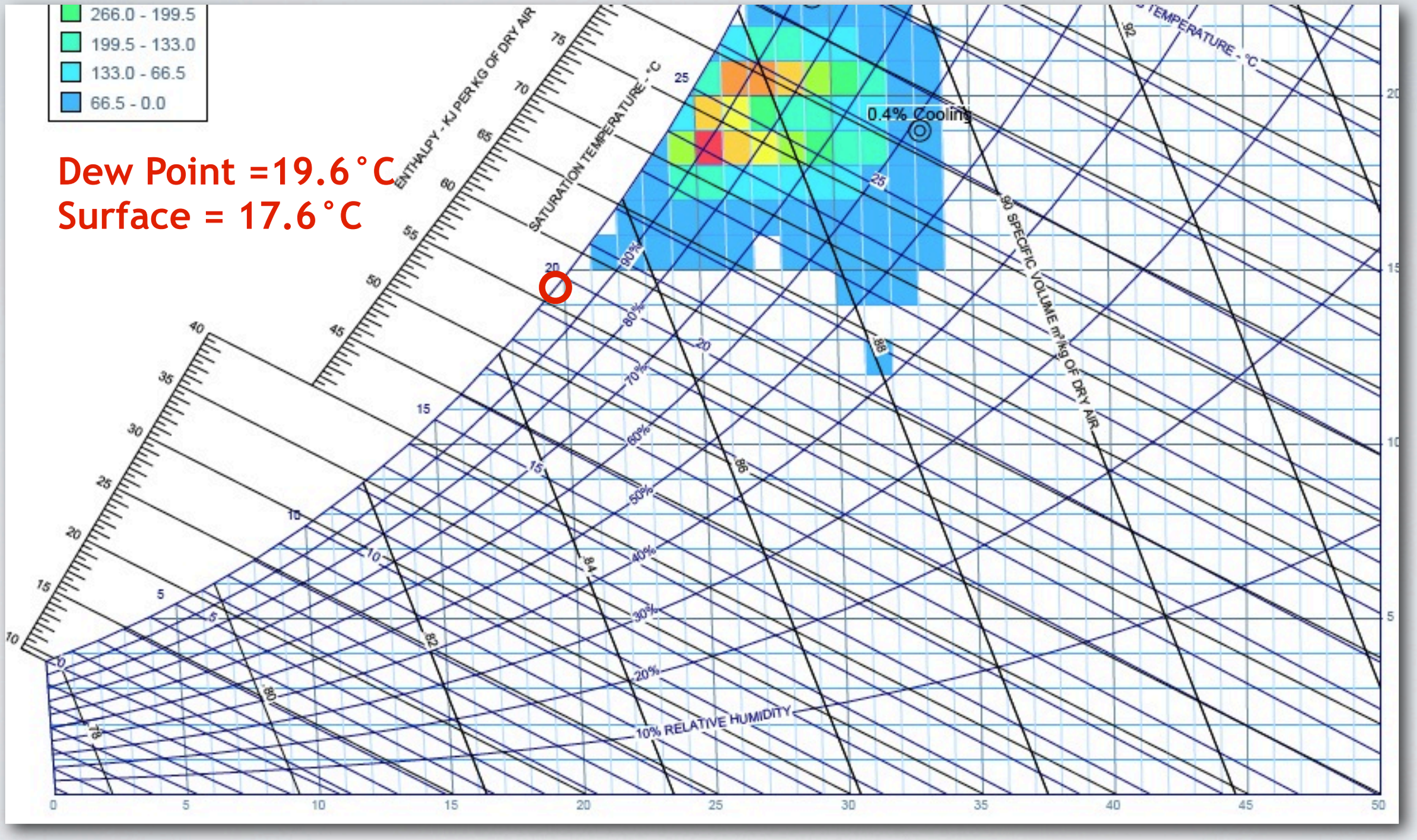

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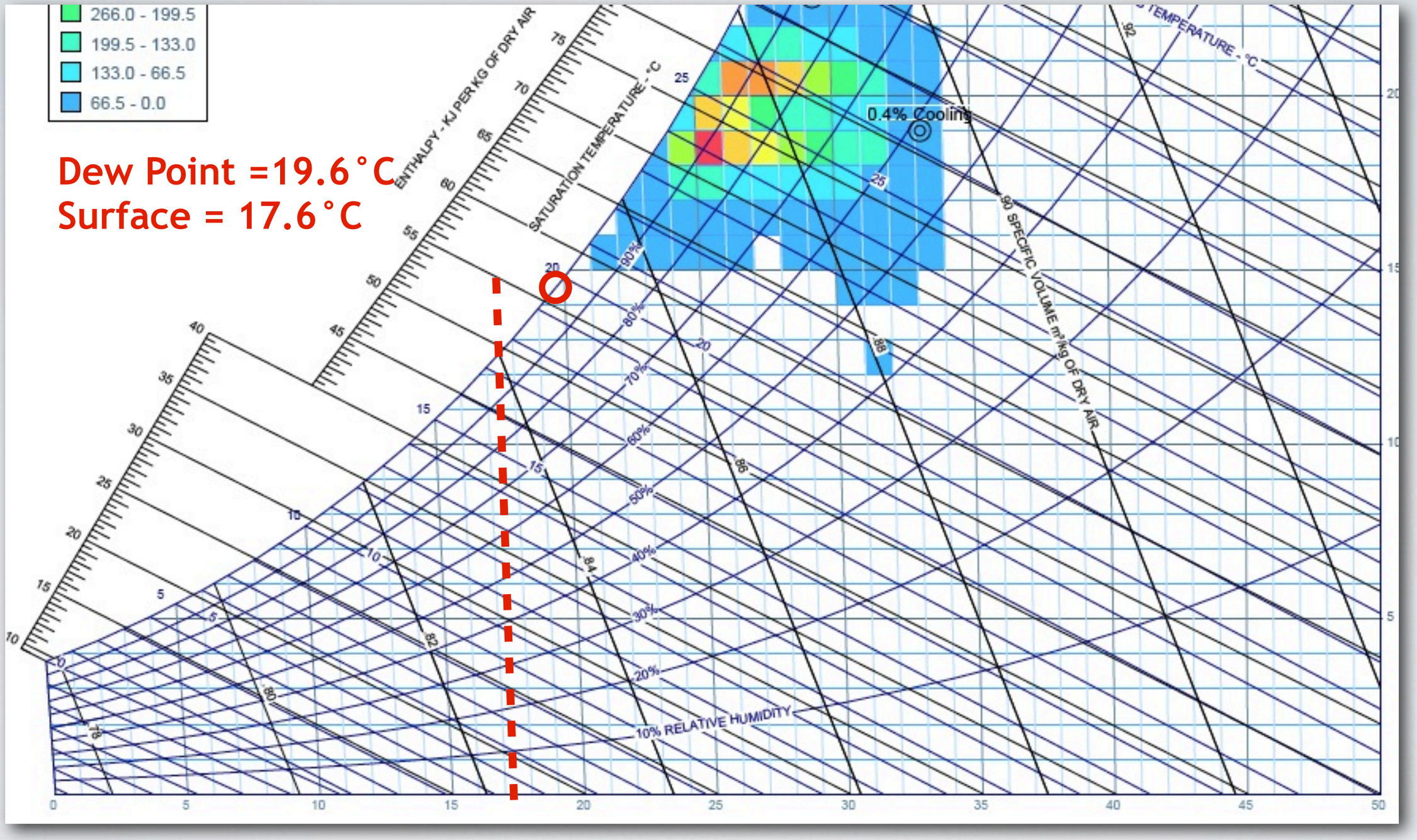

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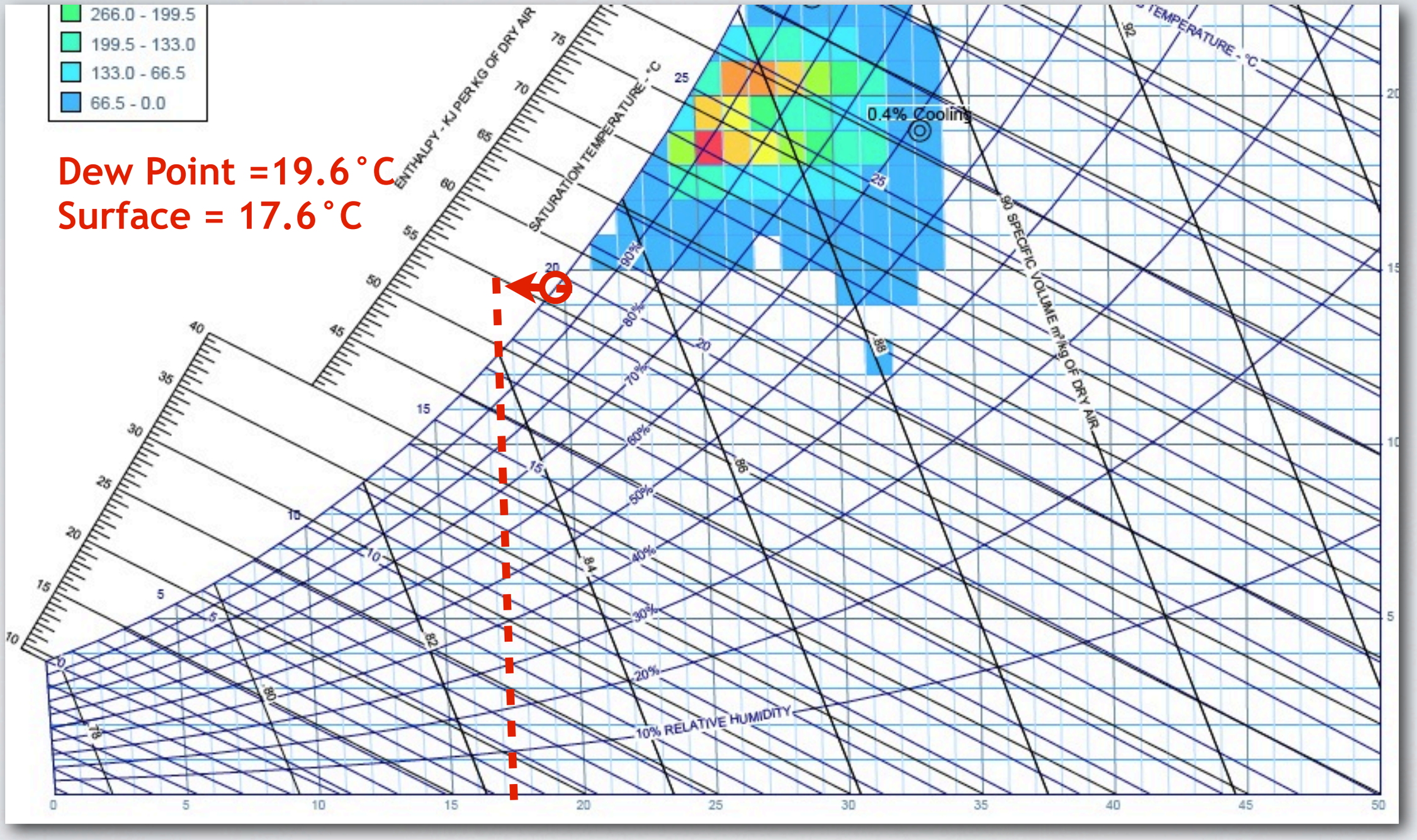

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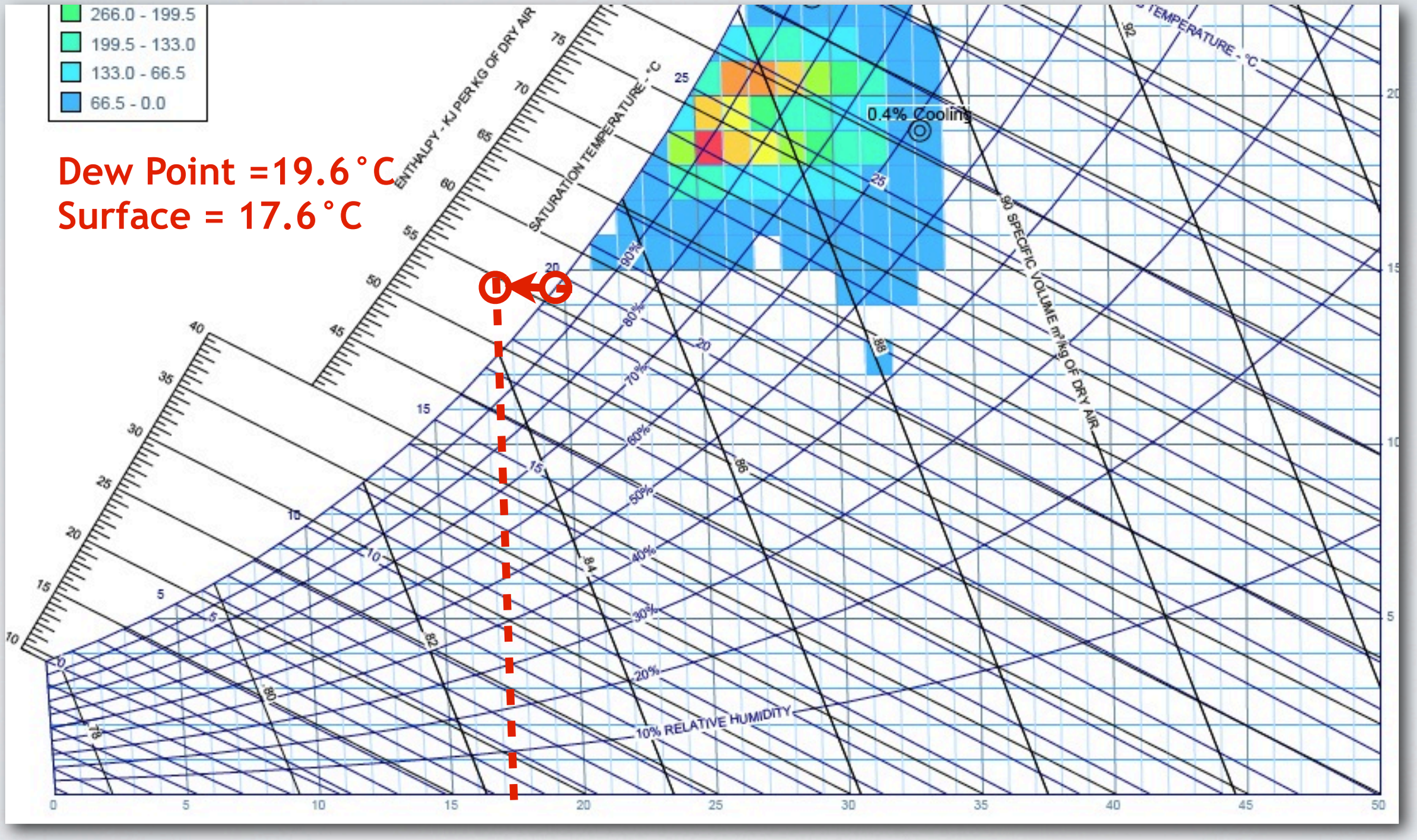

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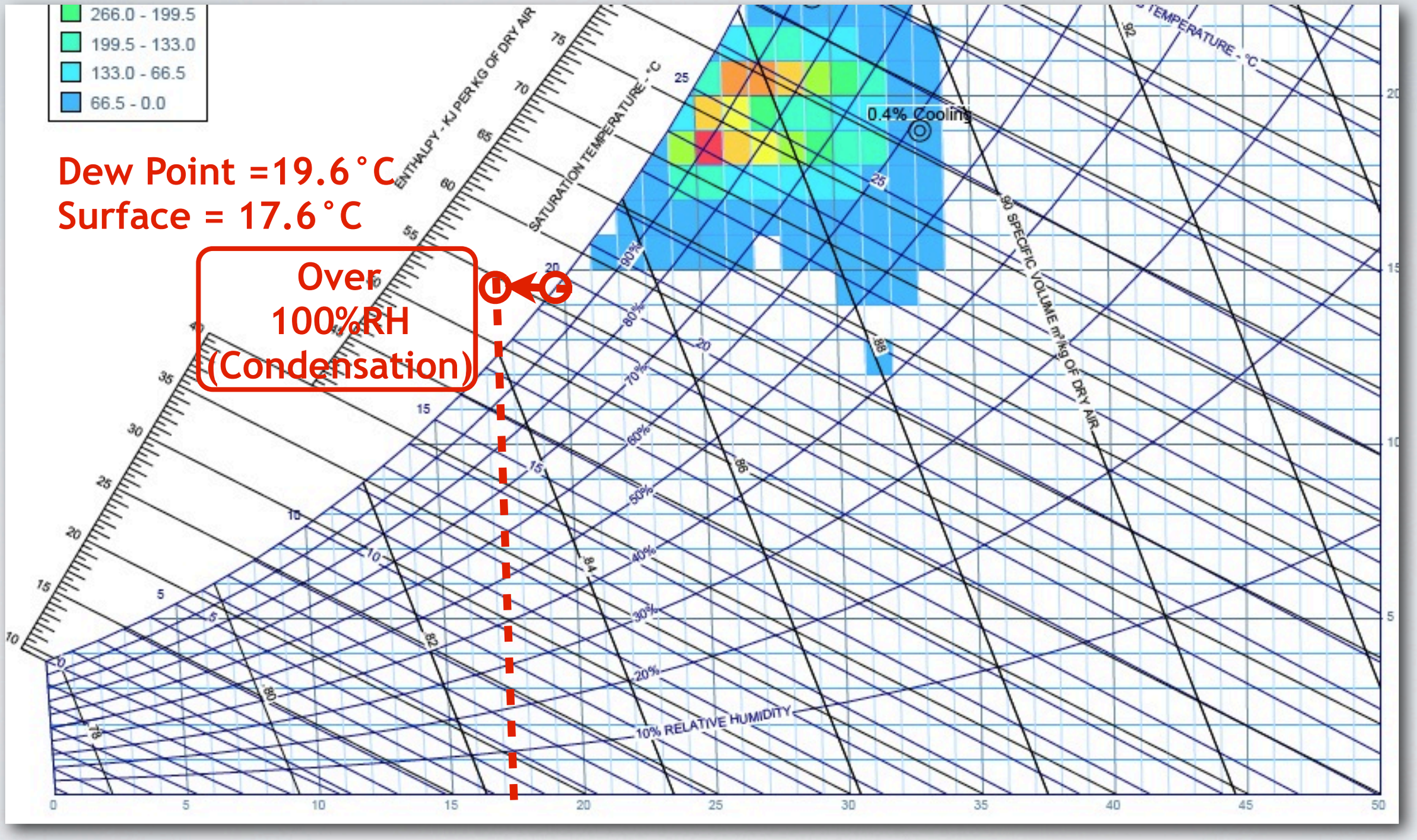
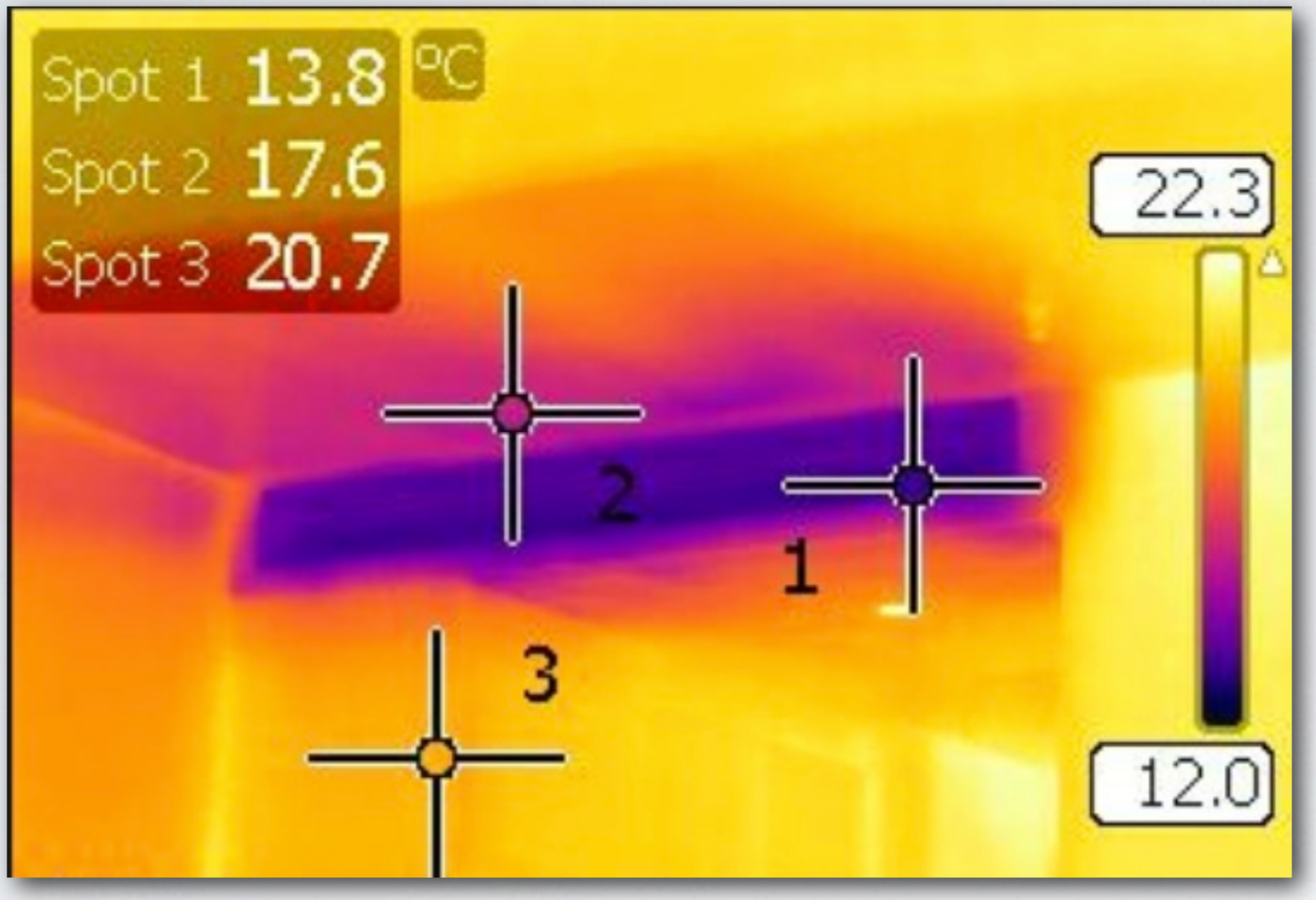


What is the mold risk for the walls of **Lew's hotel room** if the dew point stays at or above 19°C overnight (or over the weekends)?



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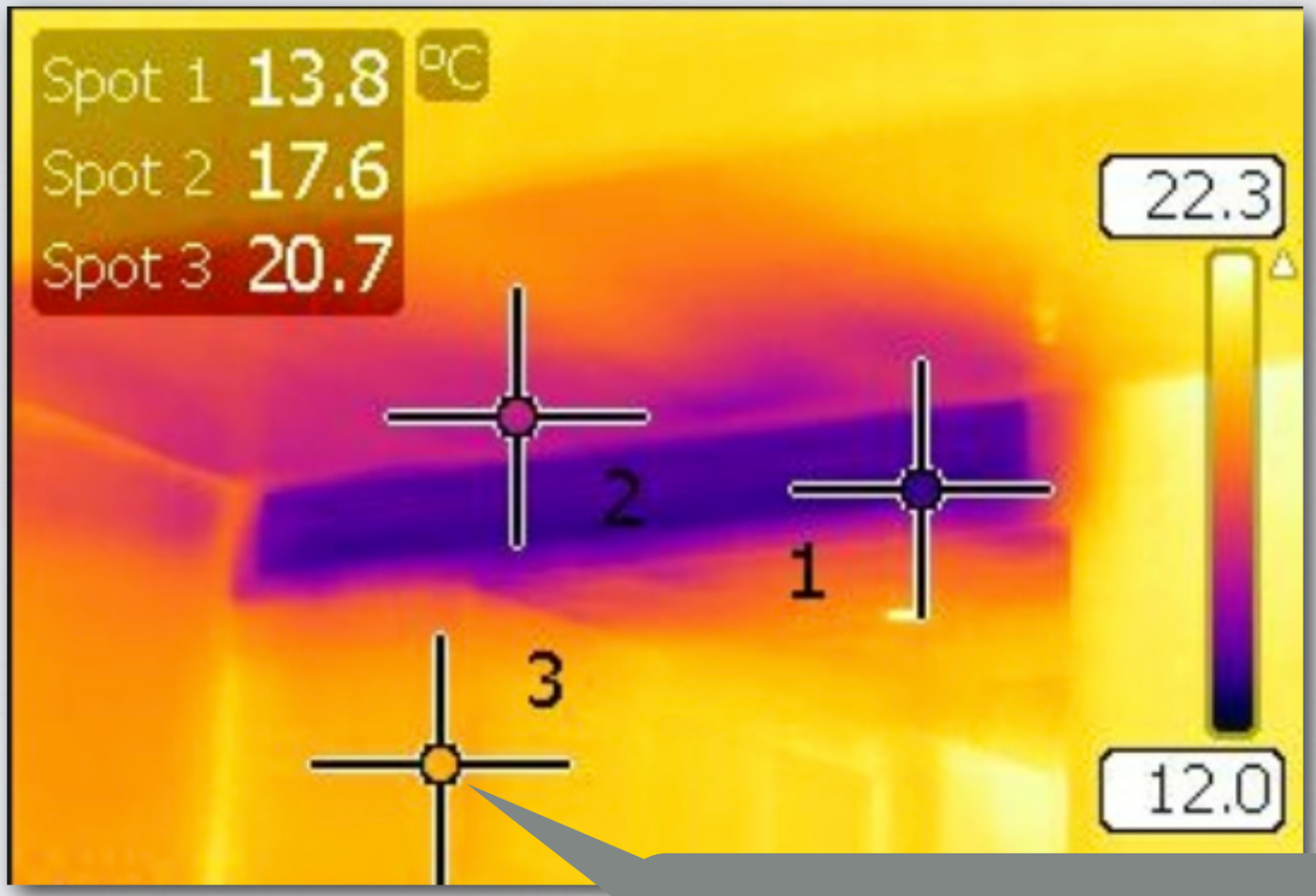


Surface RH = 95%
Mold Risk is high, over time

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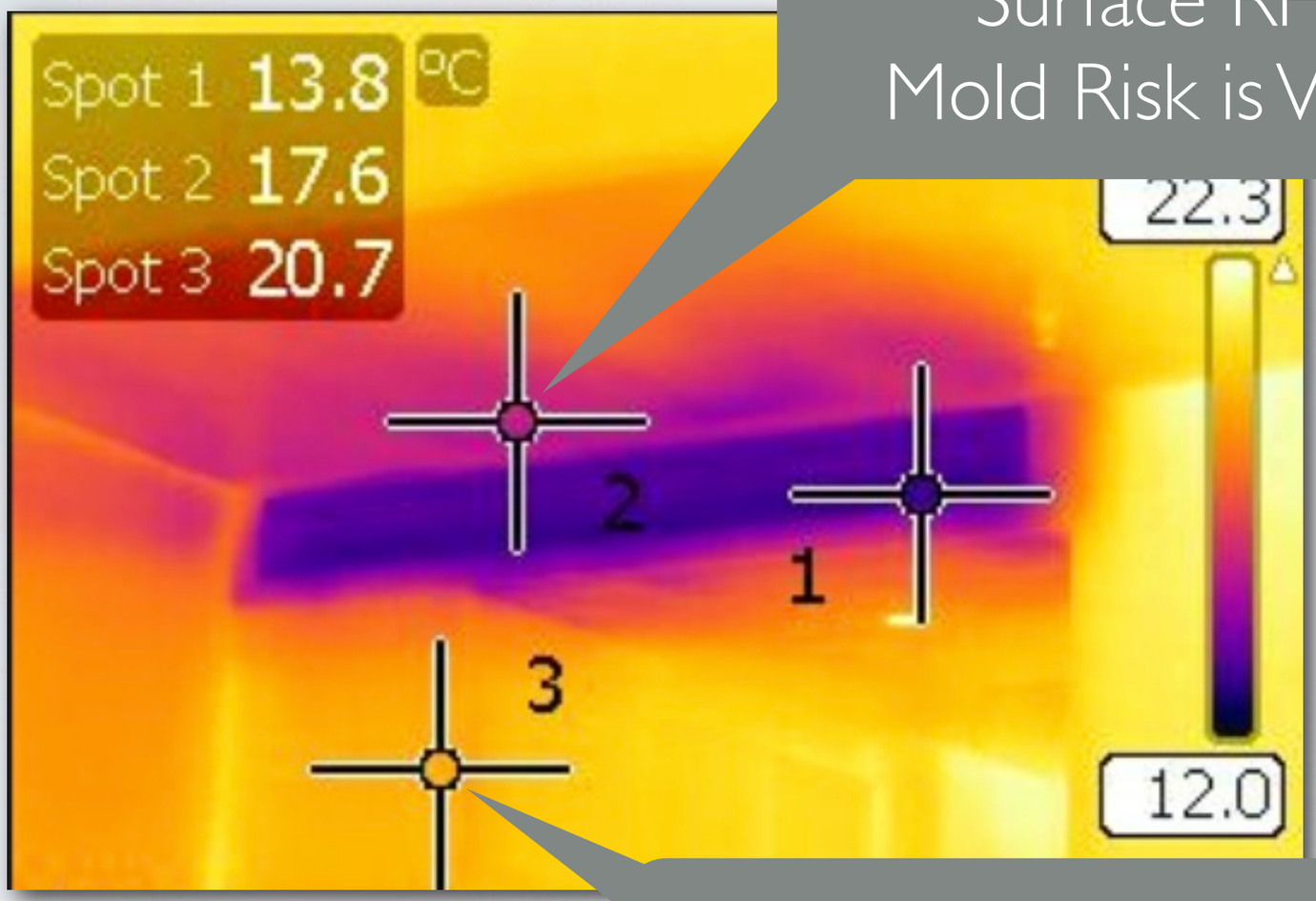


Surface RH = OVER 100%
Mold Risk is VERY high, over time

Surface RH = 95%
Mold Risk is high, over time

# Shanghai hotel room - 2010



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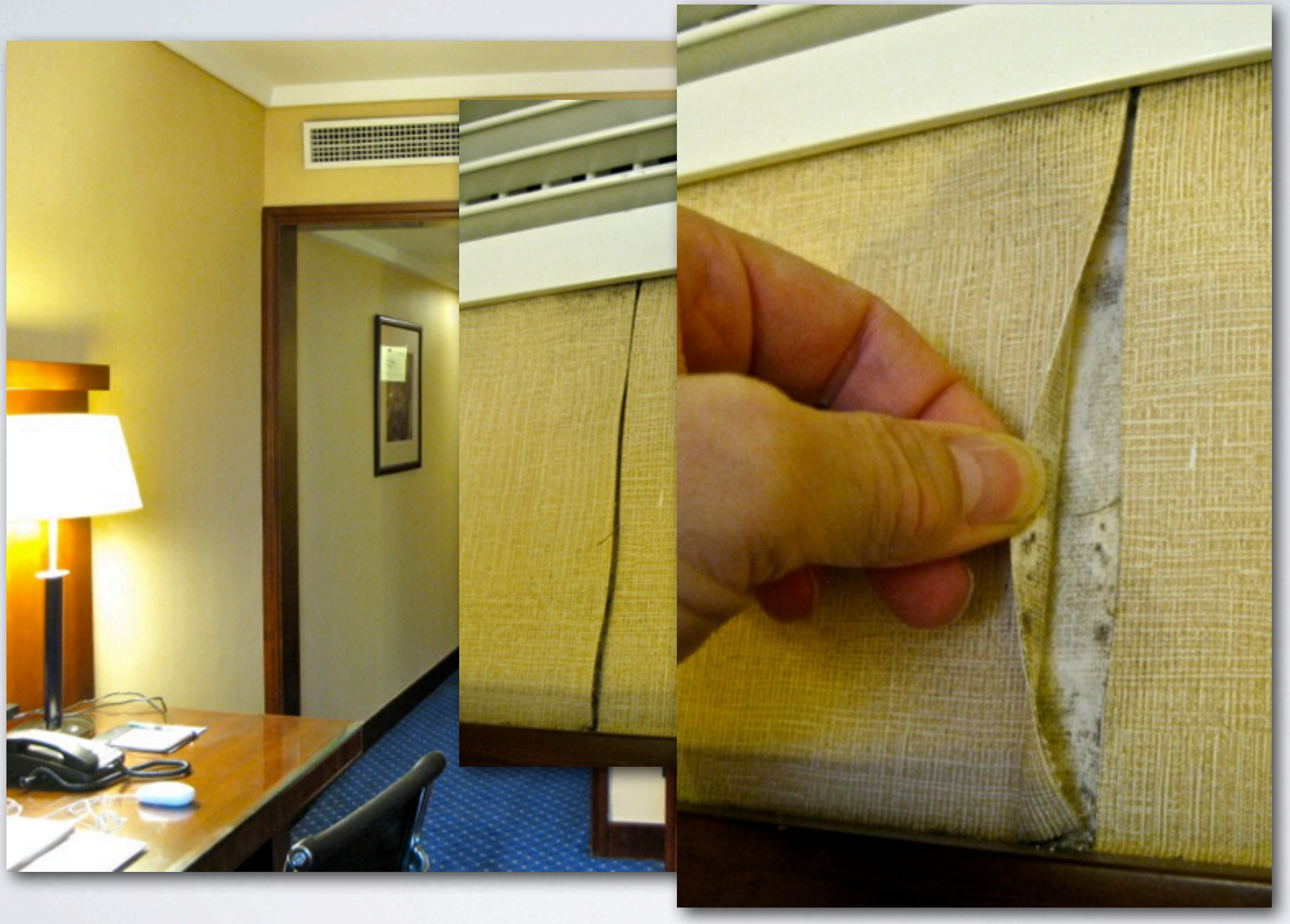

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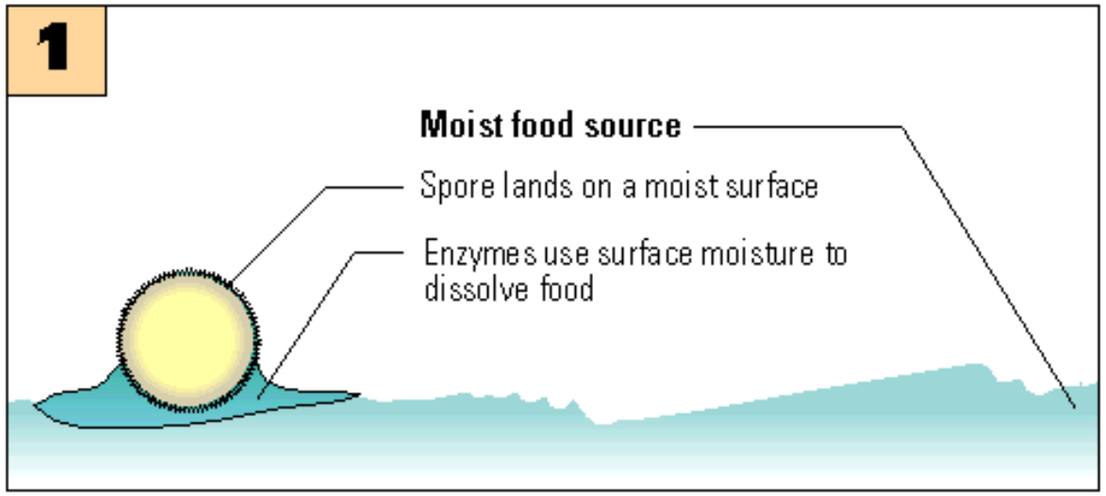
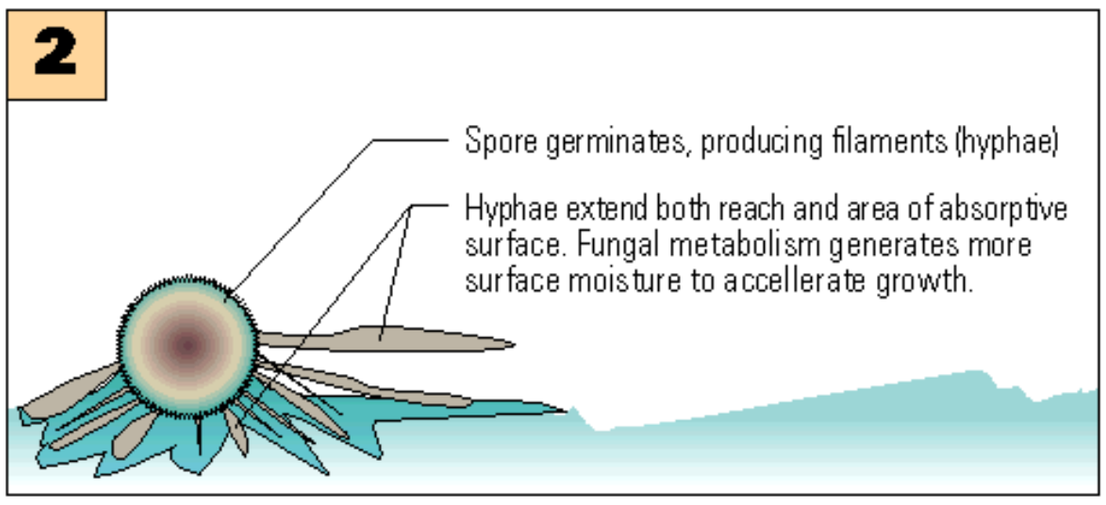
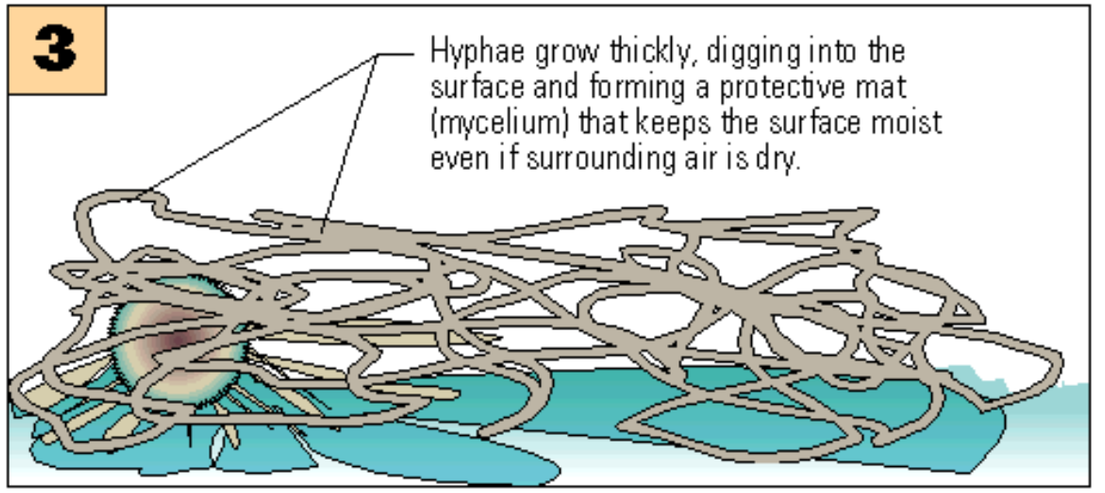
- Sealed the gaps between ducts and duct chase openings with sheet metal and spray foam.
- Installed desiccant DH unit which operates after AC units turn off at 5:00pm. DH keeps indoor air near or below 55°F dew point.
- No more comfort problems. Nearly no mold problems. There is a cost to operating the desiccant DH, but much less than operating cooling units.

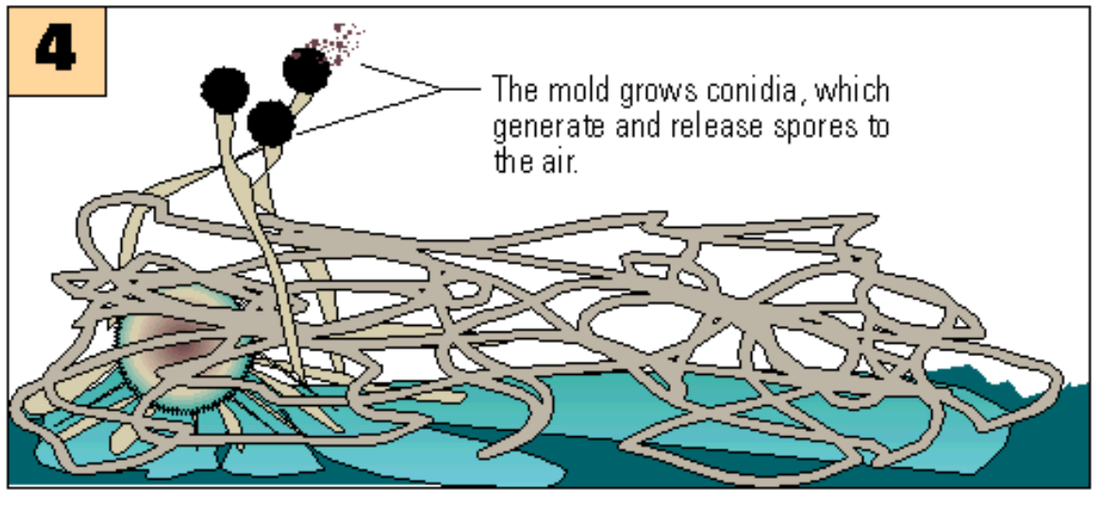
# Understanding mold growth in buildings

## Mold only cares about moisture in it's food - not RH

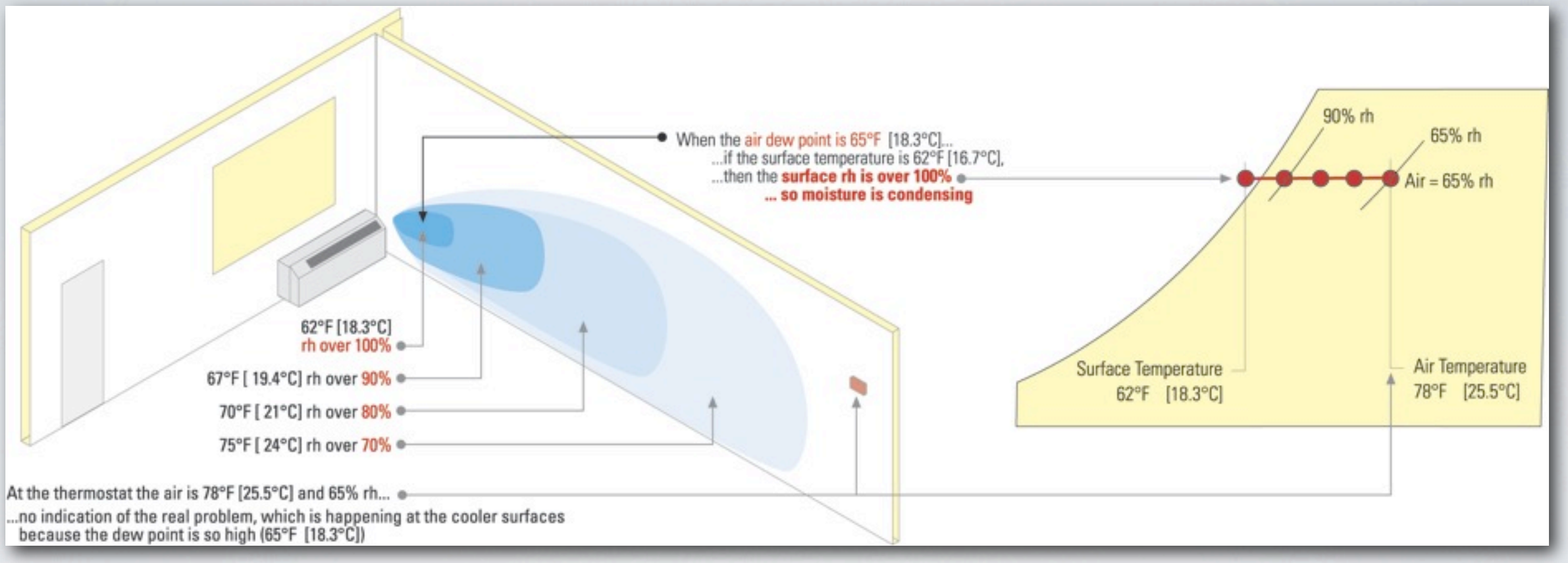


# RH in the air.. vs. RH at the surface



# Moldy building example



# Moldy building example



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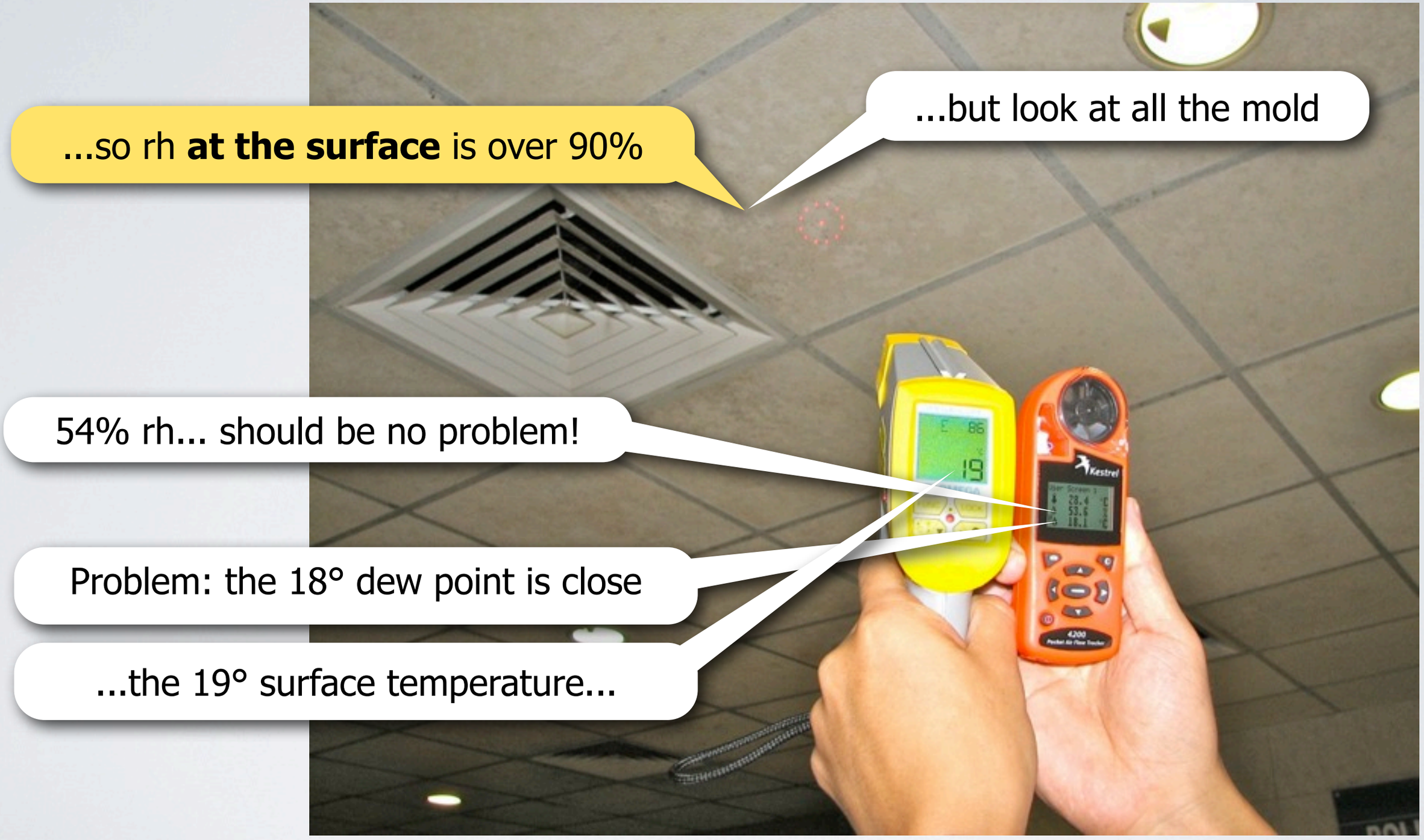


# Mold growth is greatest on coldest surfaces



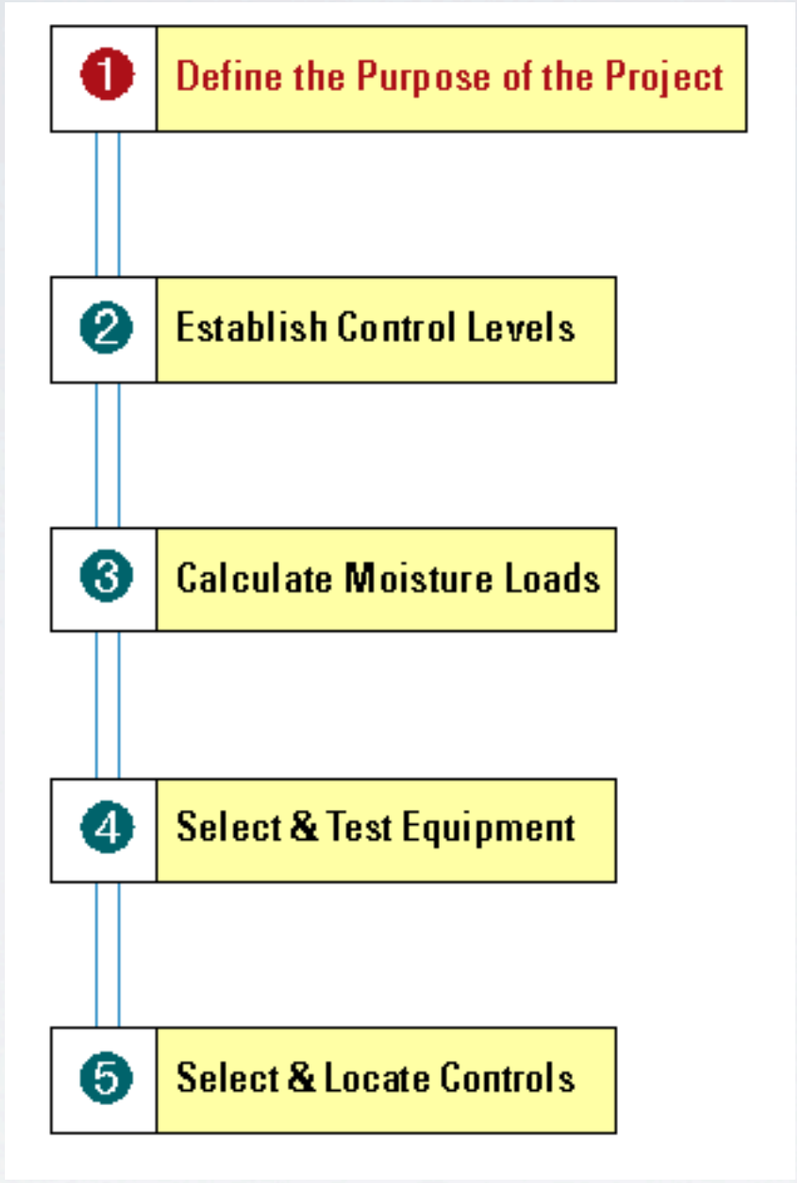
# Too much cooling leads to moisture absorption, and then to mold



## Section 2a of 3

# Humidity Control Design

# Designing for humidity control - 5-part sequence



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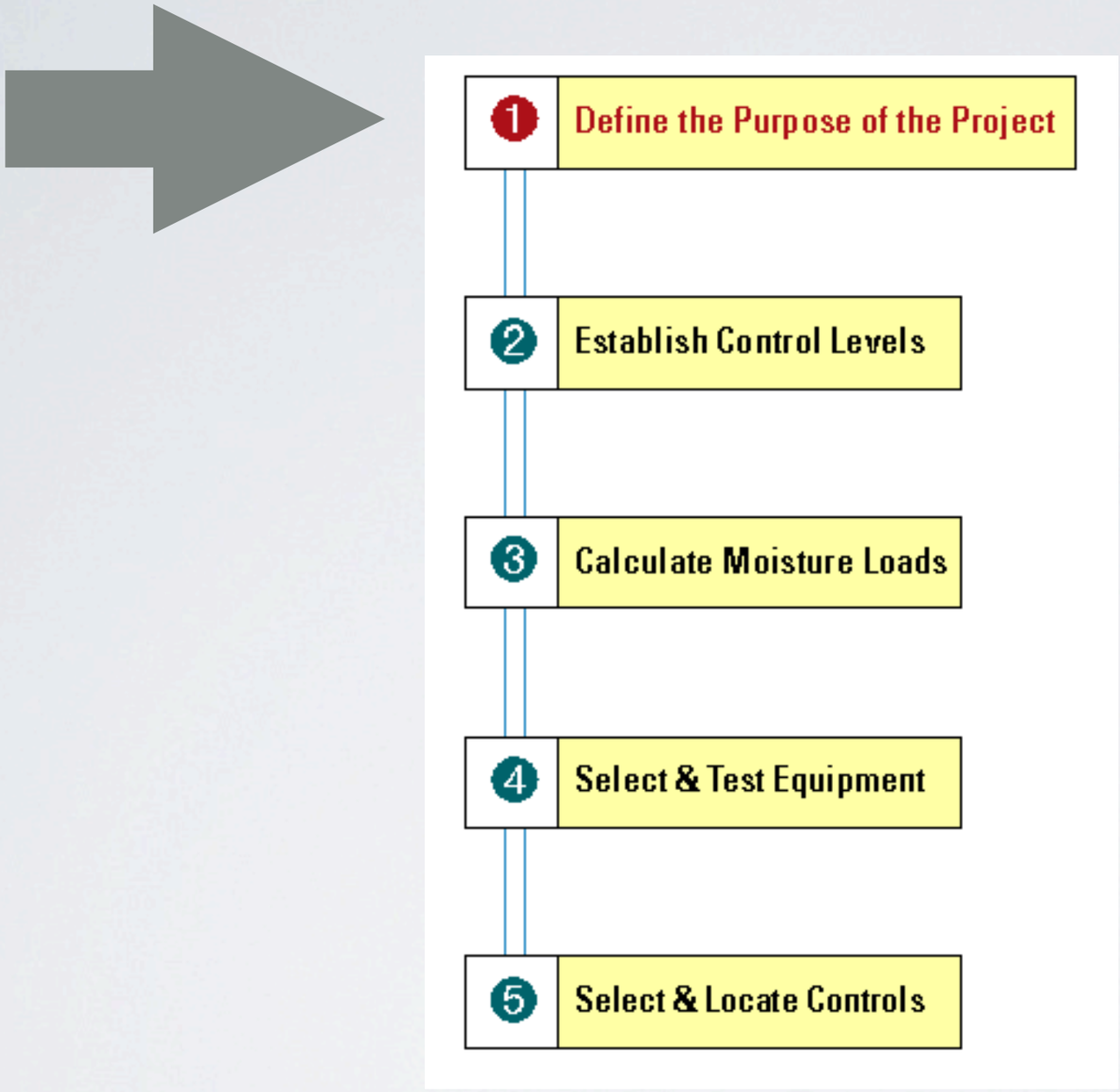


# Defining the purpose of the project

**Why insist the client define the purpose?**

- If client has no problem... no reason to spend money on humidity control.
- If consequences are not defined… impossible to say what that budget must be… and impossible to make rational decisions on the owner's behalf.

A good project purpose definition includes what...

- Results are expected
- Happens when the results are NOT achieved
- Shortcoming is acceptable

# Poor project definition

"Control the humidity within the usual limits for a hotel"

Does not define what the system must accomplish...

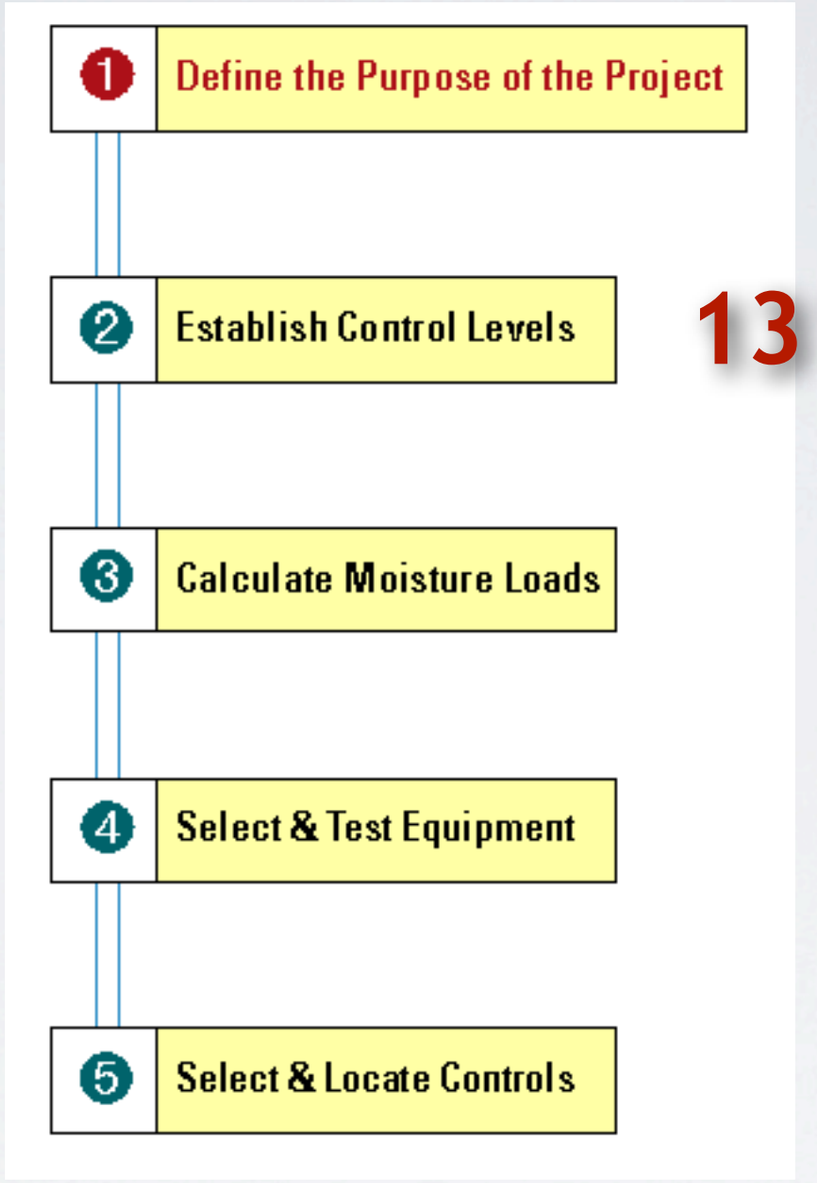
- Human comfort?
- Control everywhere?... or just in the pool area?
- Both high and low limits?
- Always? Usually? Only when rooms are occupied?

# Good definition of project purpose

**"Control the humidity in the hotel so that..."**

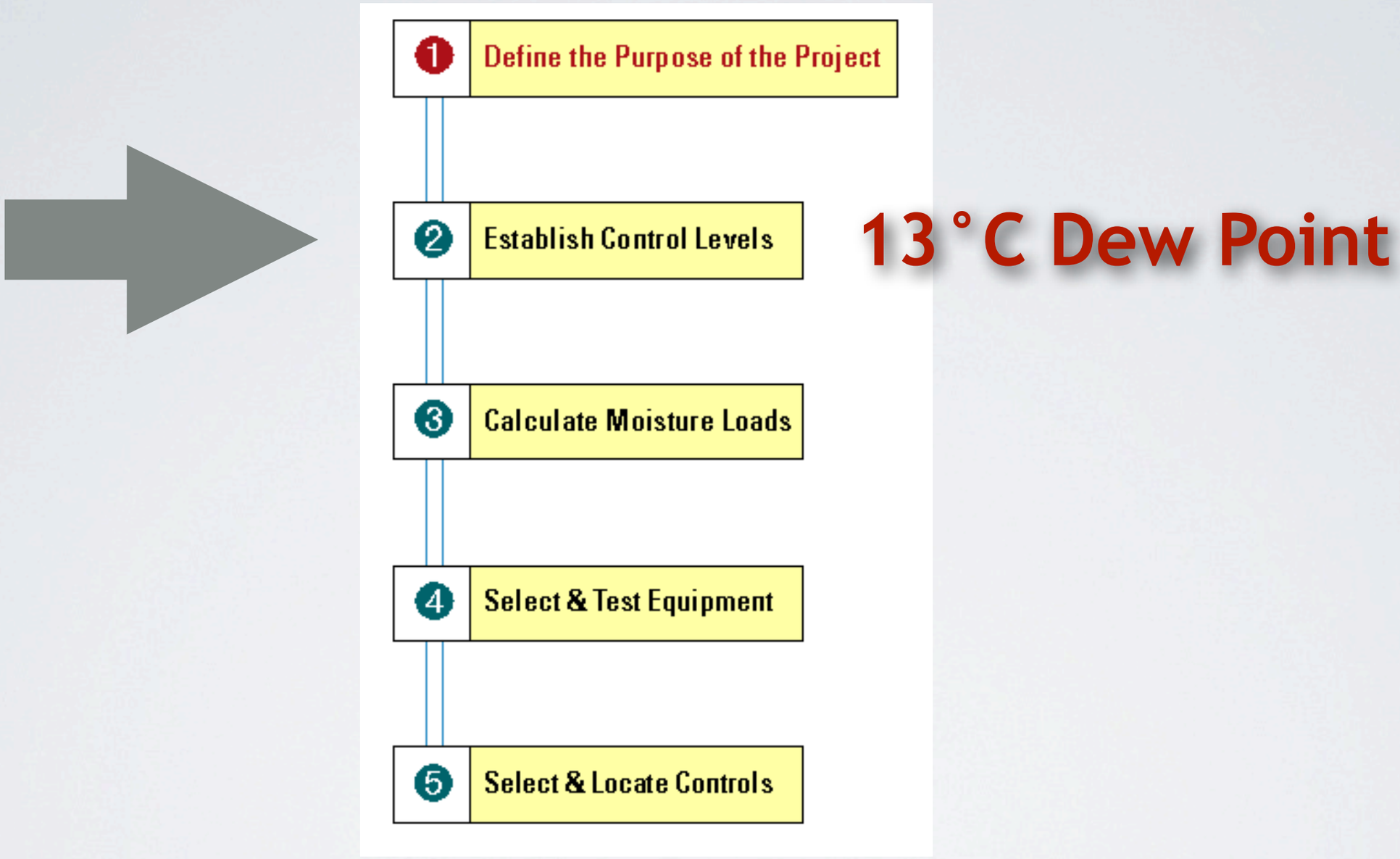
- Neither condensation nor high rh can occur in building cavities that would allow mold growth or other moisture damage to the building or its furnishings.
- Guest rooms, meeting rooms, dining rooms and offices are held within the ASHRAE comfort zones during both summer and winter seasons
- The system achieves these goals during all but 2% of the hours in a typical year.

# Step 2 - Establish control level that achieves purpose for humidity control



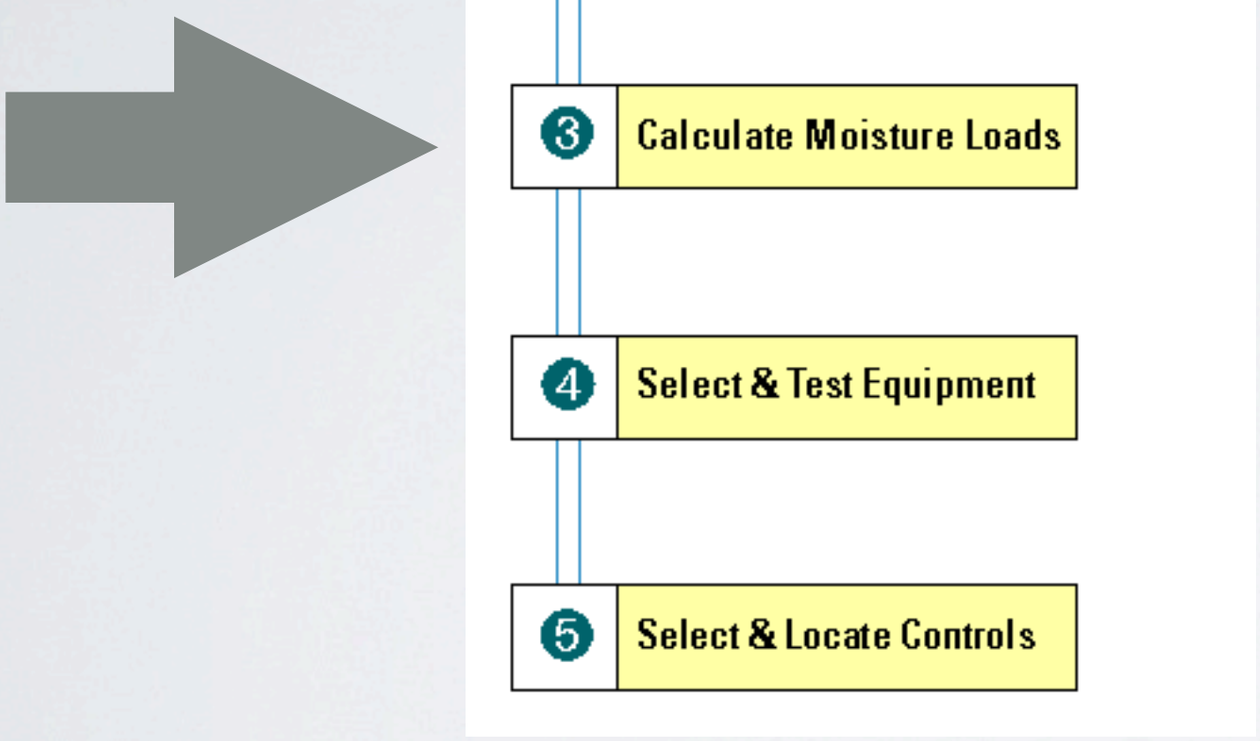

**13°C Dew Point**

# Step 2 - Establish control level that achieves purpose for humidity control




**13°C Dew Point**

# Step 3 - Calculate the humidity loads



# Step 3 - Calculate the humidity loads



1. Define the Purpose of the Project
2. Establish Control Levels
3. Calculate Moisture Loads
4. Select & Test Equipment
5. Select & Locate Controls

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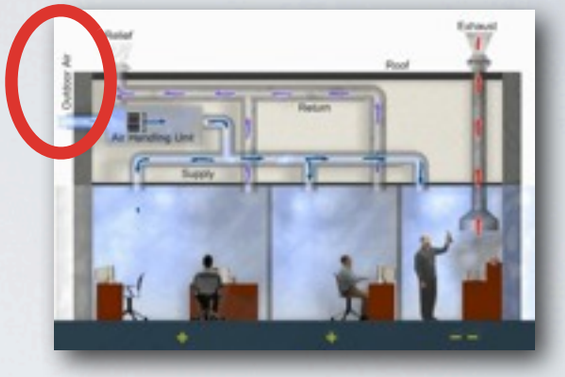

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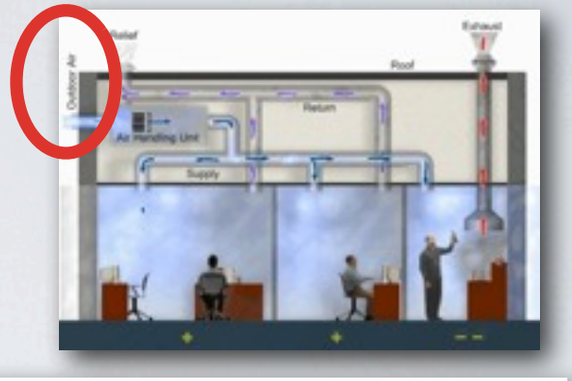


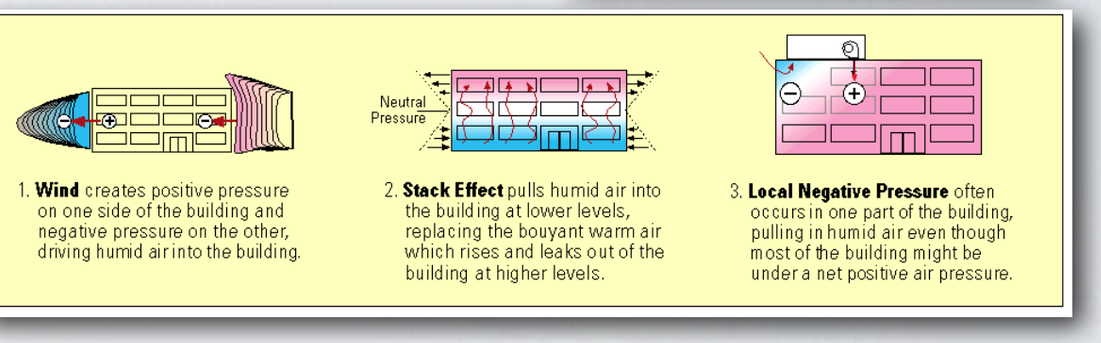


1. **Wind** creates positive pressure on one side of the building and negative pressure on the other, driving humid air into the building.
2. **Stack Effect** pulls humid air into the building at lower levels, replacing the bouyant warm air which rises and leaks out of the building at higher levels.
3. **Local Negative Pressure** often occurs in one part of the building, pulling in humid air even though most of the building might be under a net positive air pressure.

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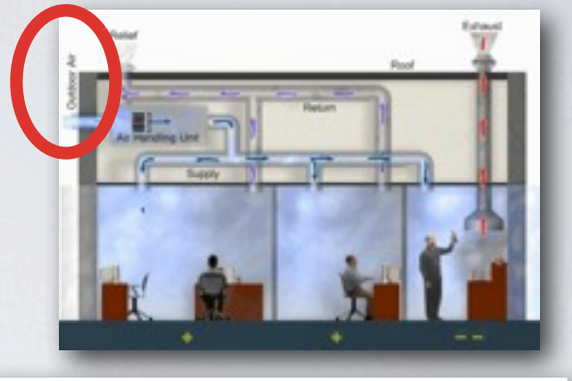


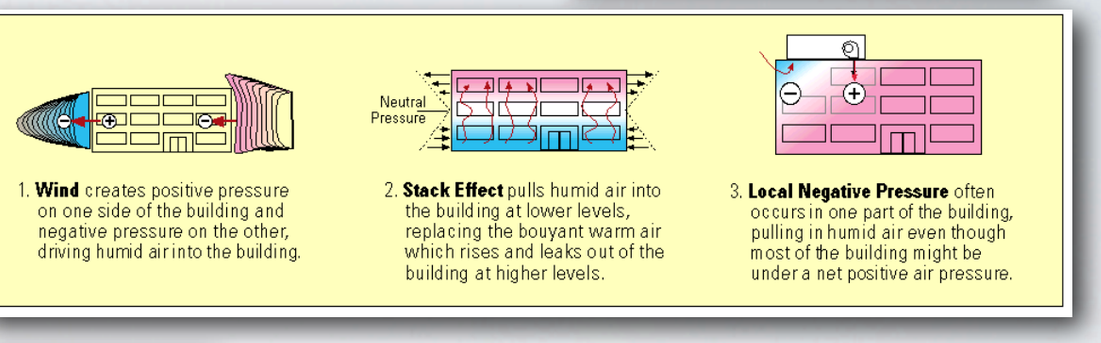


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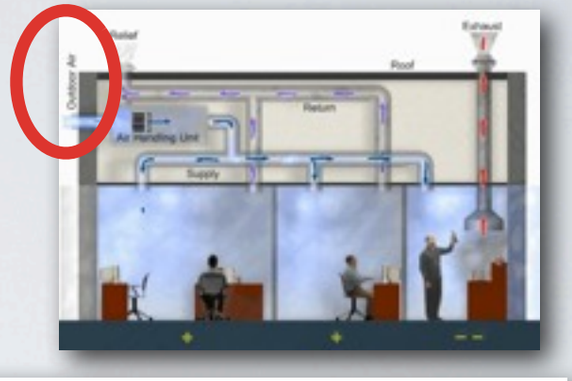


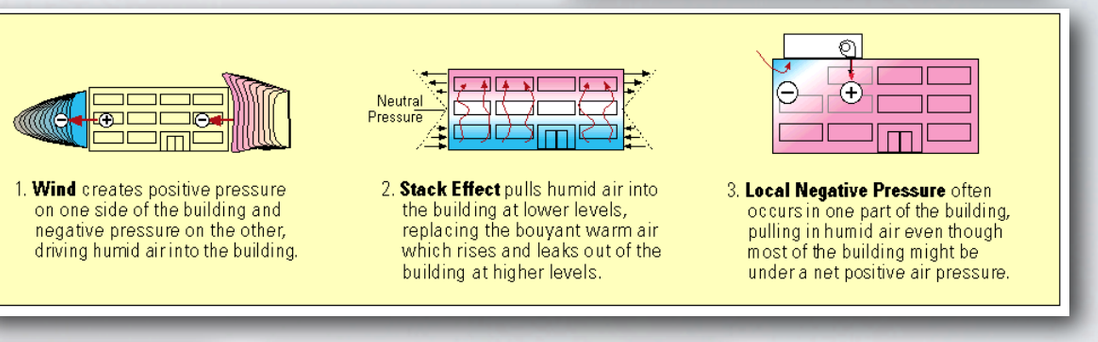




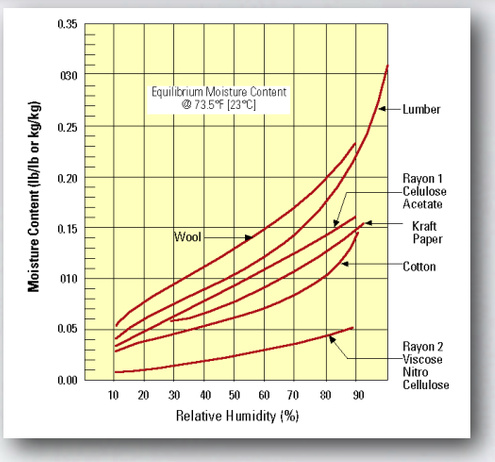

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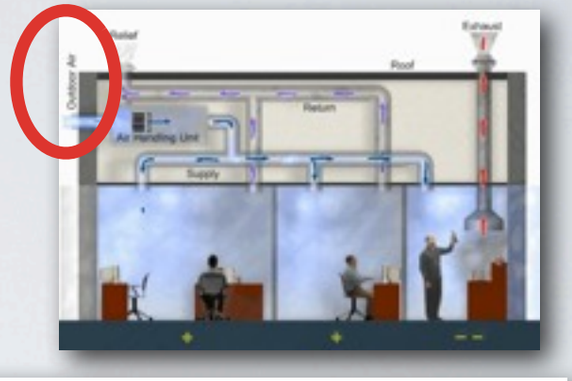
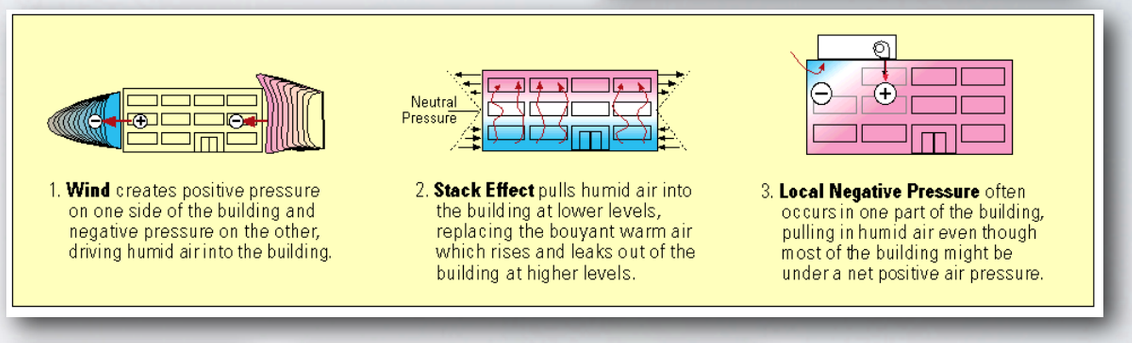
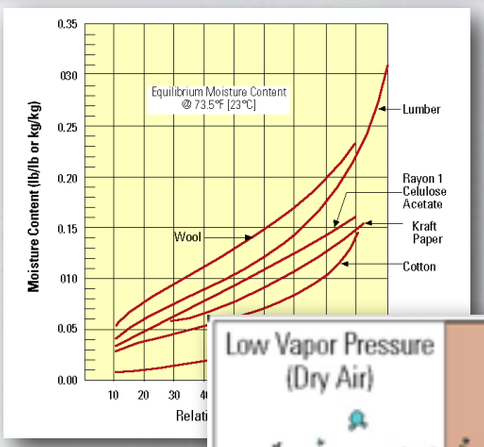
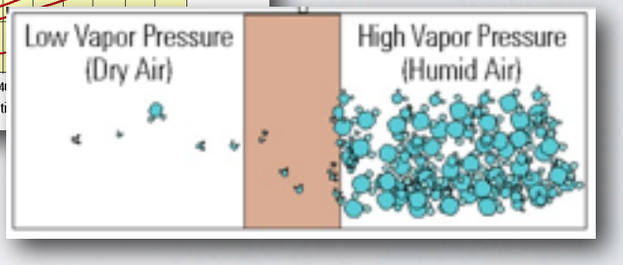


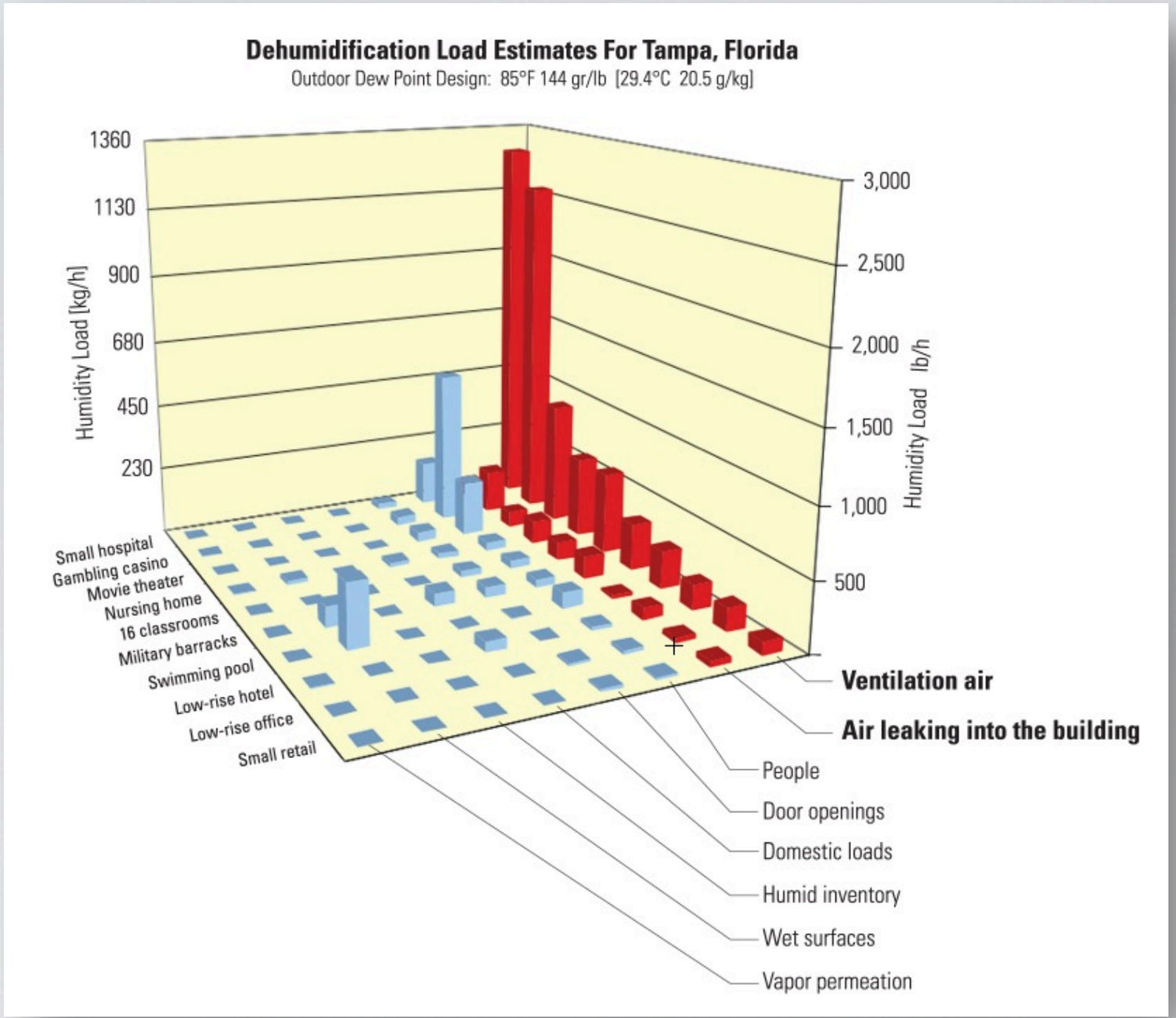





# Largest loads?
# Ventilation/makeup air and infiltration



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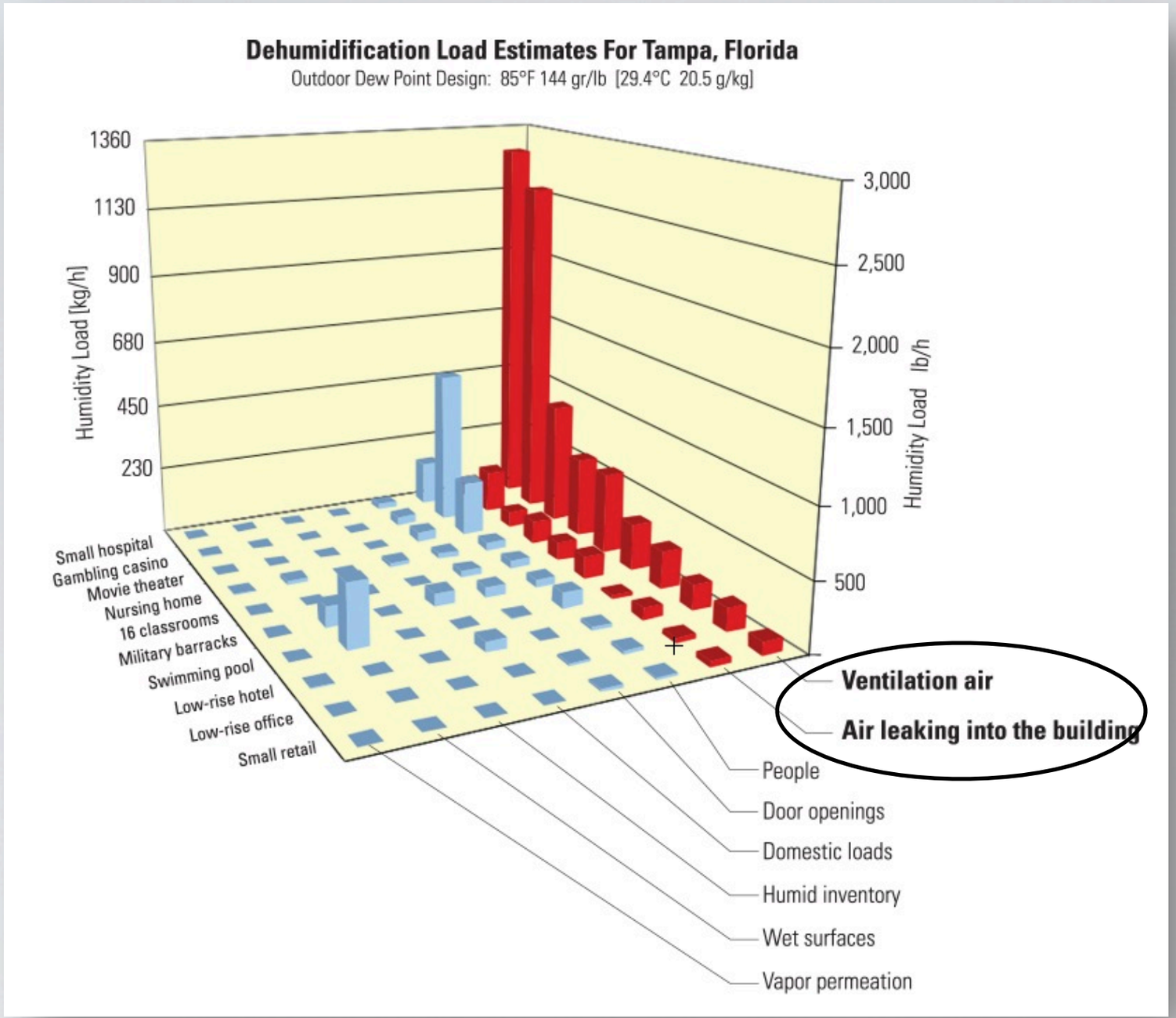
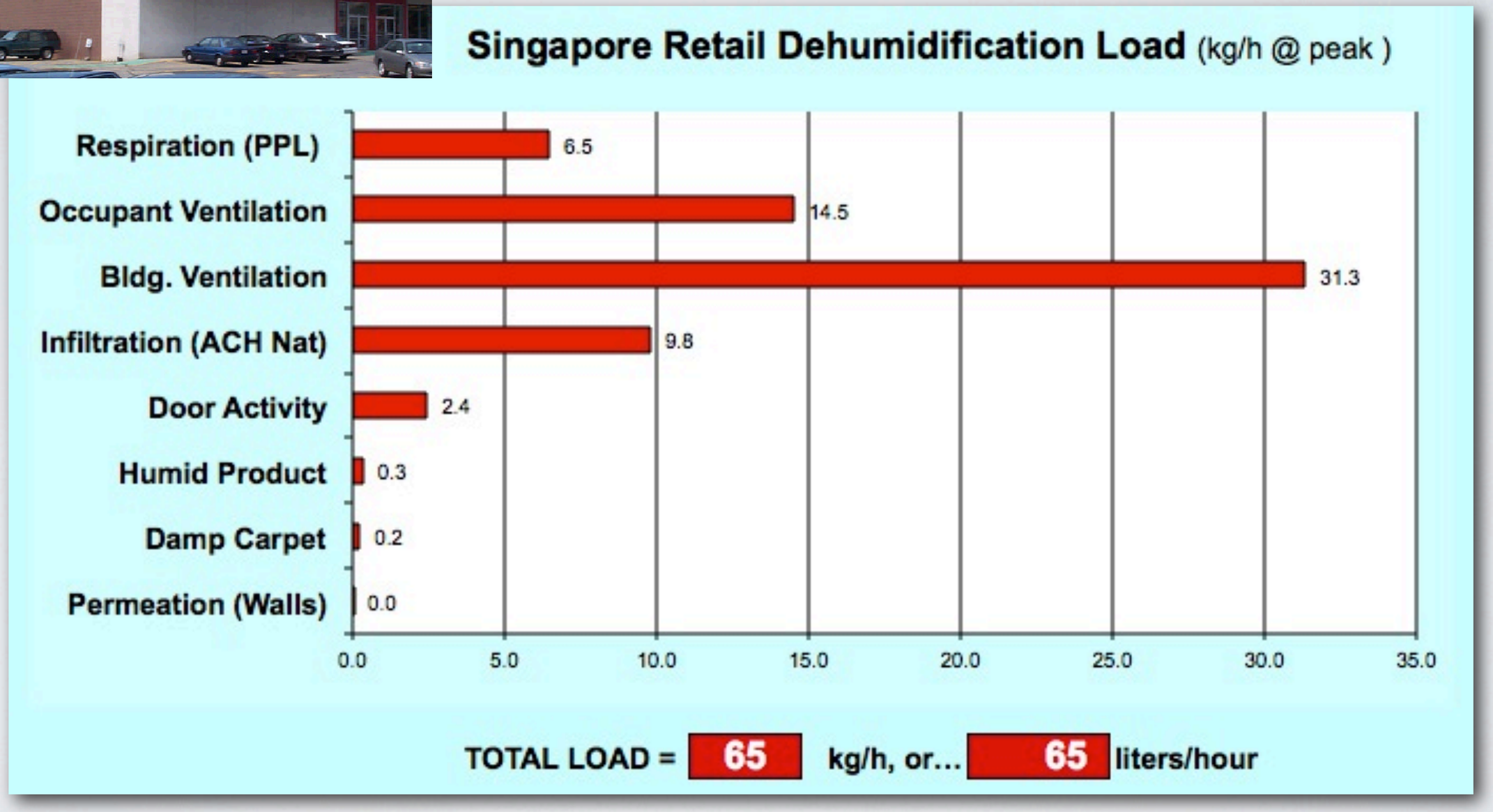


# Retail building in Singapore - Humidity load estimate



# Retail building in Singapore - Humidity load estimate




Ventilation to dilute contaminants from people

**Singapore Retail Dehu…ification Load** (kg/h @ peak )

| | |
|---|---|
| Respiration (PPL) | 6.5 |
| Occupant Ventilation | 14.5 |
| Bldg. Ventilation | 31.3 |
| Infiltration (ACH Nat) | 9.8 |
| Door Activity | 2.4 |
| Humid Product | 0.3 |
| Damp Carpet | 0.2 |
| Permeation (Walls) | 0.0 |

0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0

**TOTAL LOAD = 65 kg/h, or... 65 liters/hour**

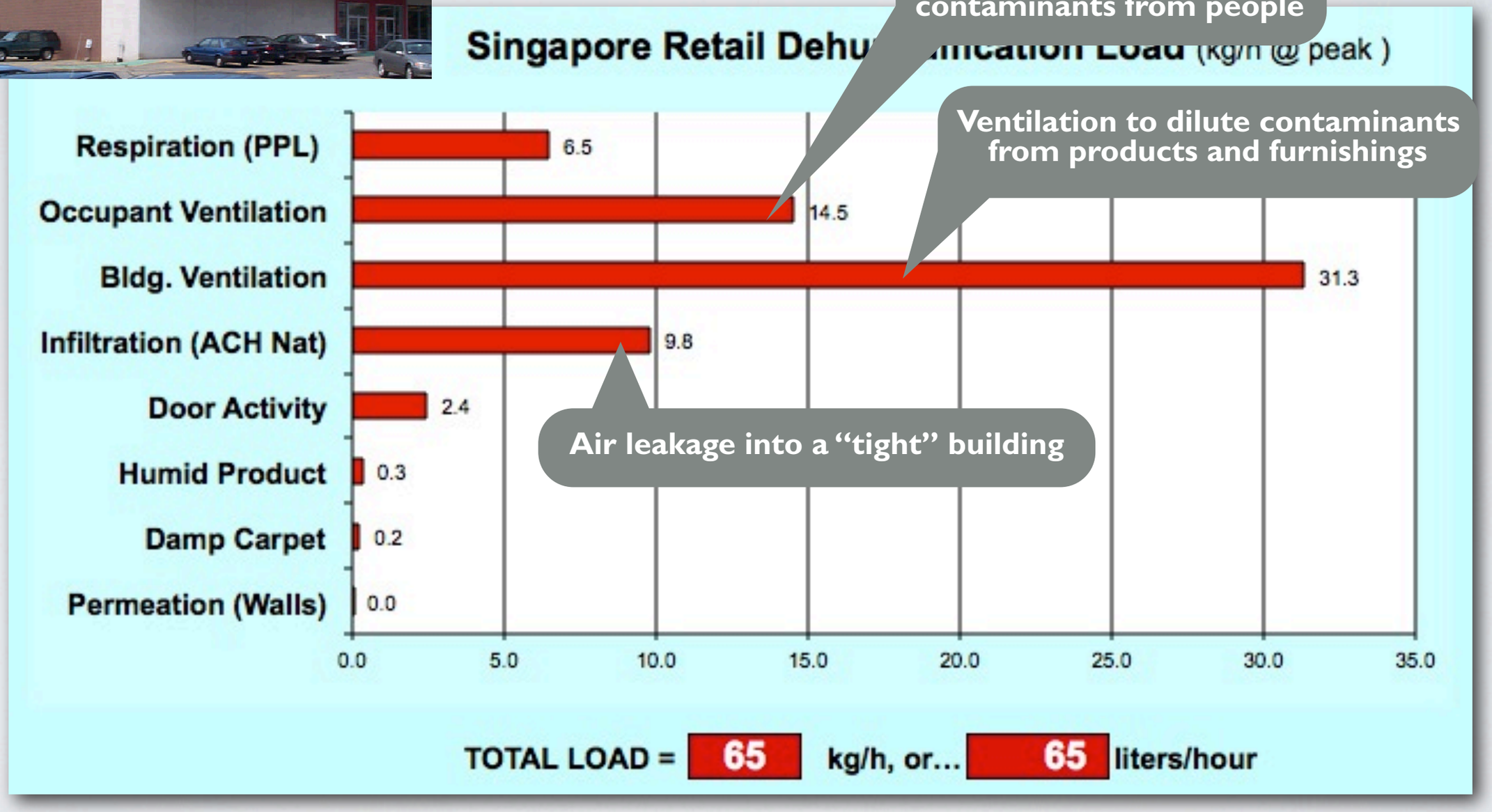
# Retail building in Singapore - Humidity load estimate






# Retail building in Singapore - Humidity load estimate



# Peak humidity loads - ASHRAE Research 1997
# Correcting 100 years of error - Now we know better

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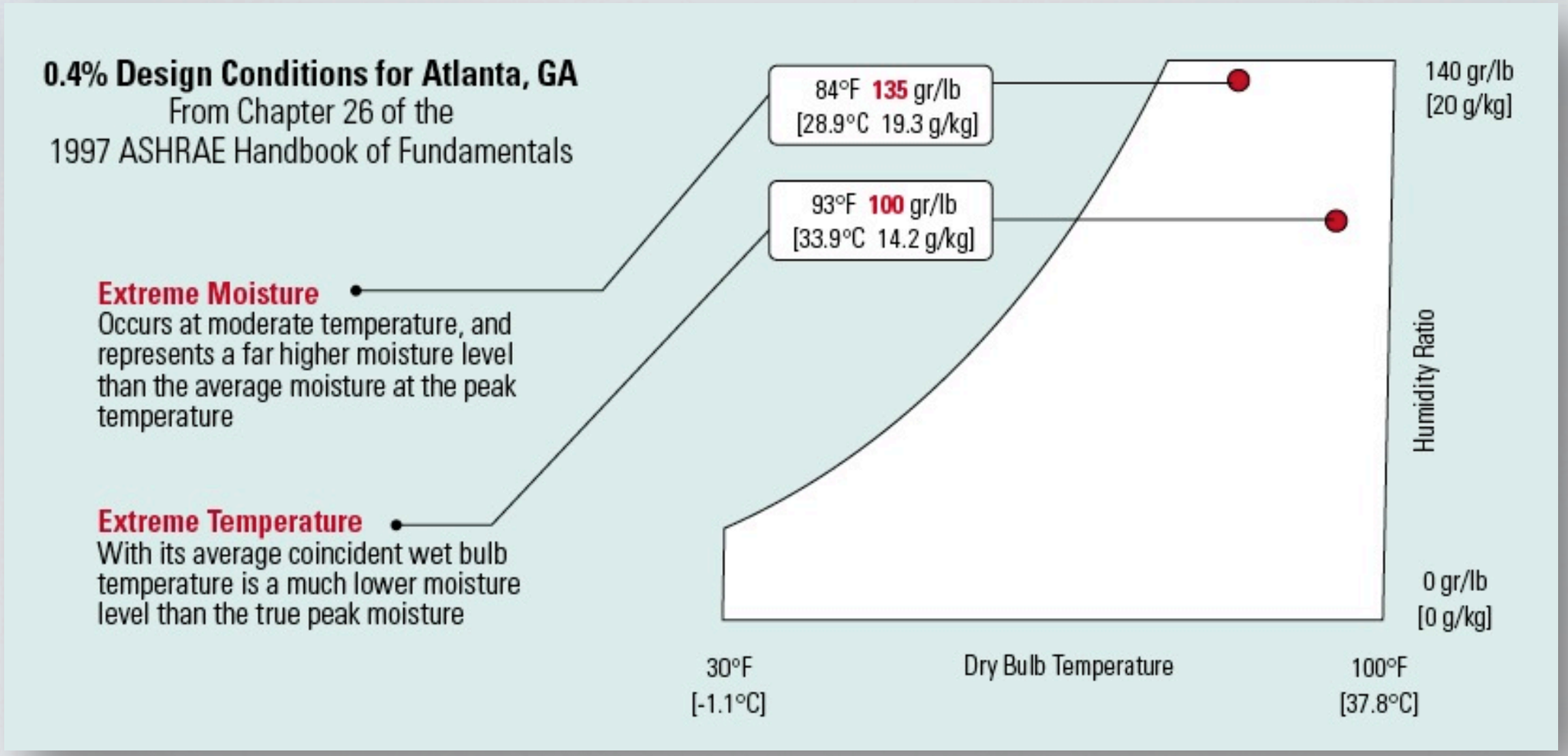
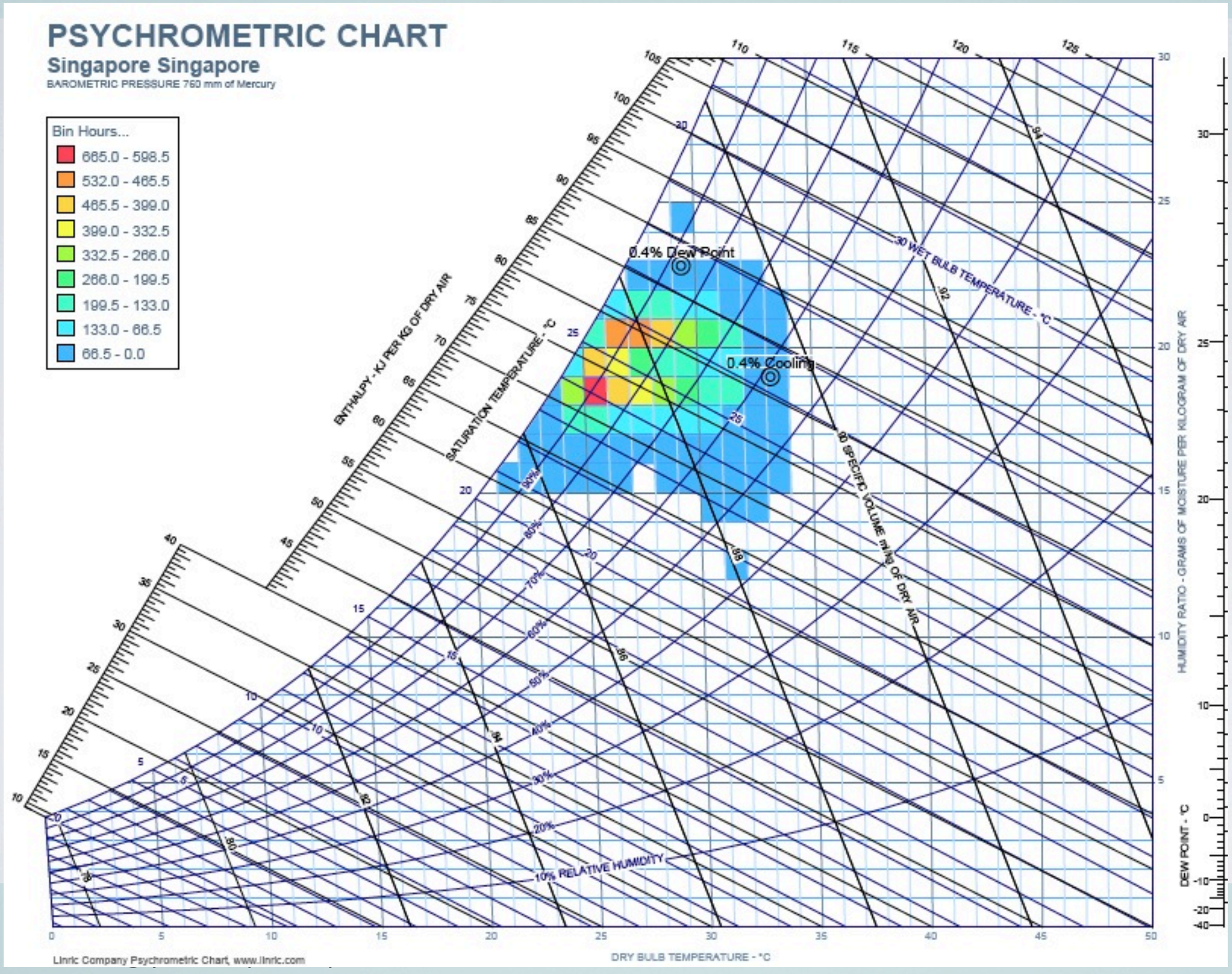


# ASHRAE Dew Point Design Values for Singapore



# How to find the peak design dew point?
# ASHRAE Fundamentals - 1997 or later

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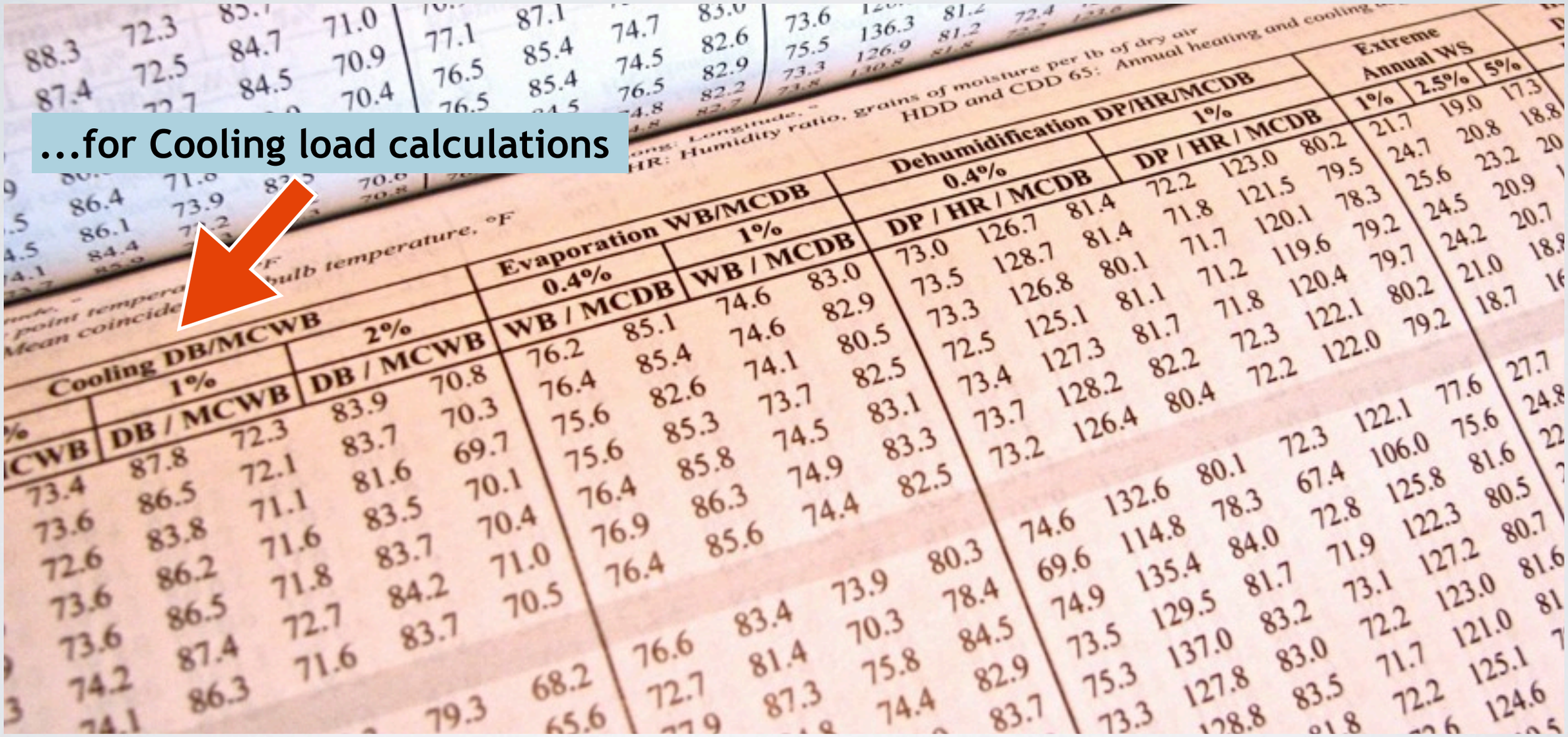
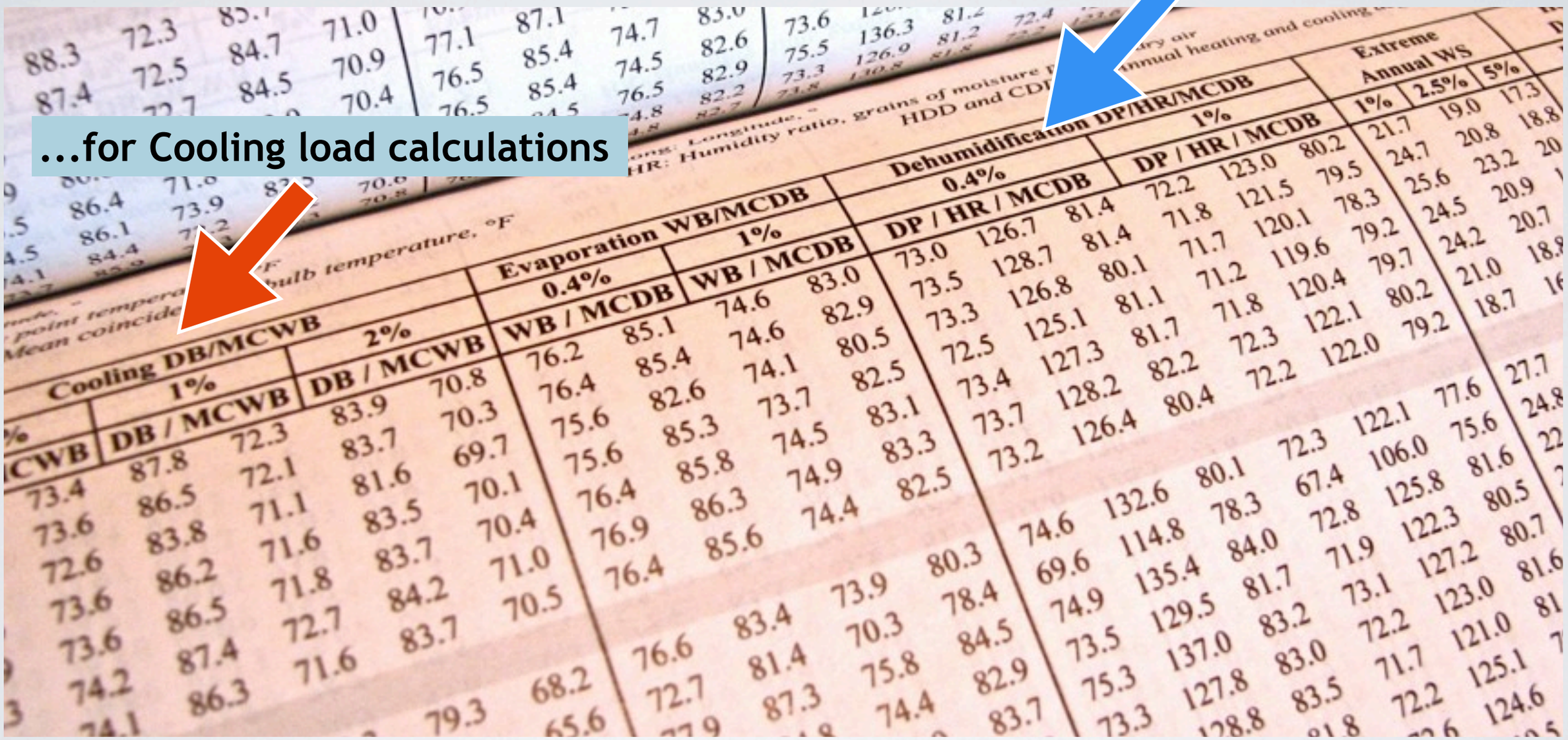


# How to find the peak design dew point?
# ASHRAE Fundamentals - 1997 or later

**...for dehumidification load calculations, and DOAS system design**

**...for Cooling load calculations**



# Singapore - ASHRAE peak humidity design conditions

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| 0.4% Dry Bulb |
| --- |
| **33.2°** DB<br>26.3° MCWB |
| 19.0 g/kg |

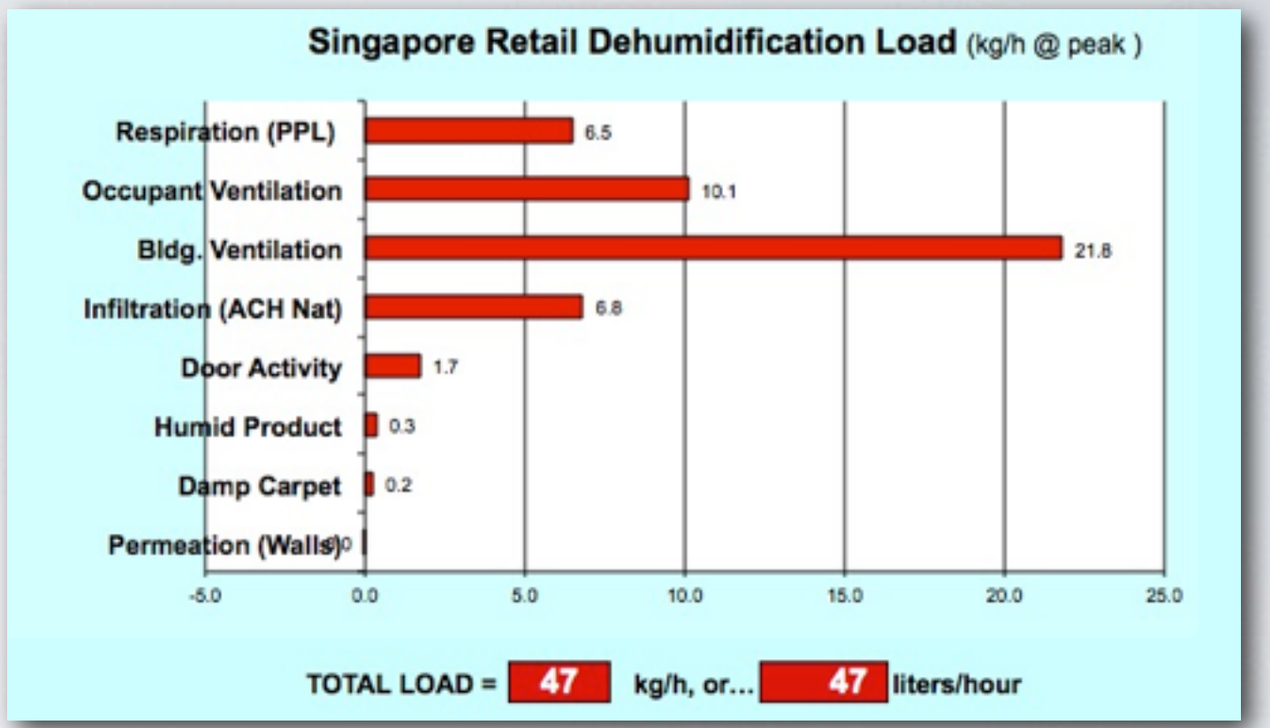
# Singapore - ASHRAE peak humidity design conditions

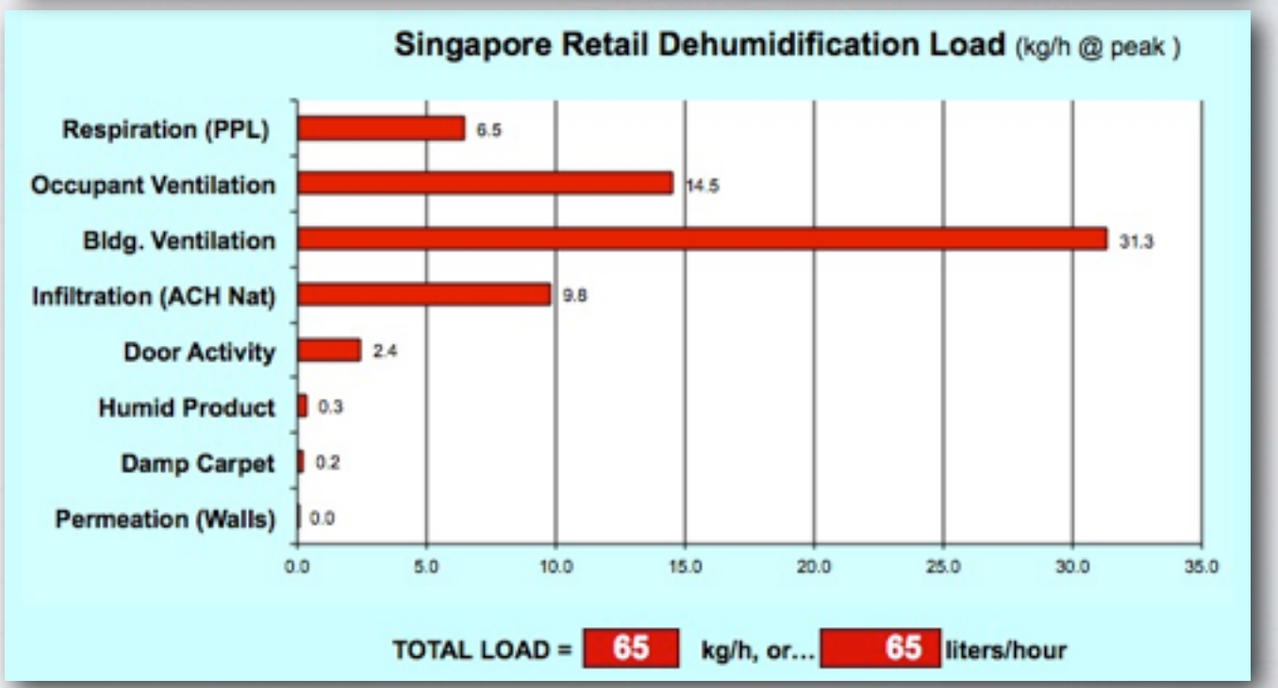
| 0.4% Dry Bulb | 0.4% Dew Point |
|---|---|
| **33.2°** DB<br>26.3° MCWB | **29.4°**DB<br>27.6°MCWB |
| 19.0 g/kg | 22.8 g/kg |

# Singapore - ASHRAE peak humidity design conditions

| 0.4% Dry Bulb | 0.4% Dew Point | **Difference at peak dew point** |
|---|---|---|
| **33.2°** DB<br>26.3° MCWB | **29.4°**DB<br>27.6°MCWB | **-3.8°C DB** |
| 19.0 g/kg | 22.8 g/kg | **+3.8 g/kg** |

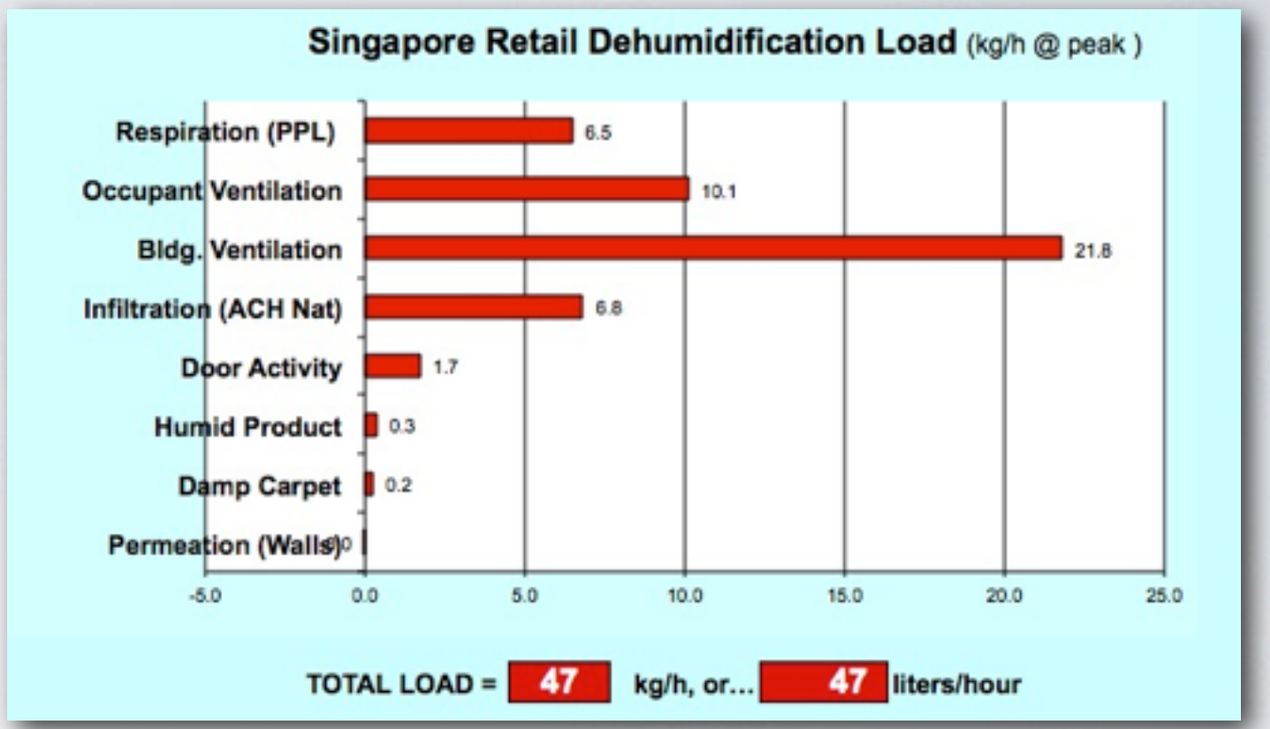
# load at peak dry bulb vs. peak dew point

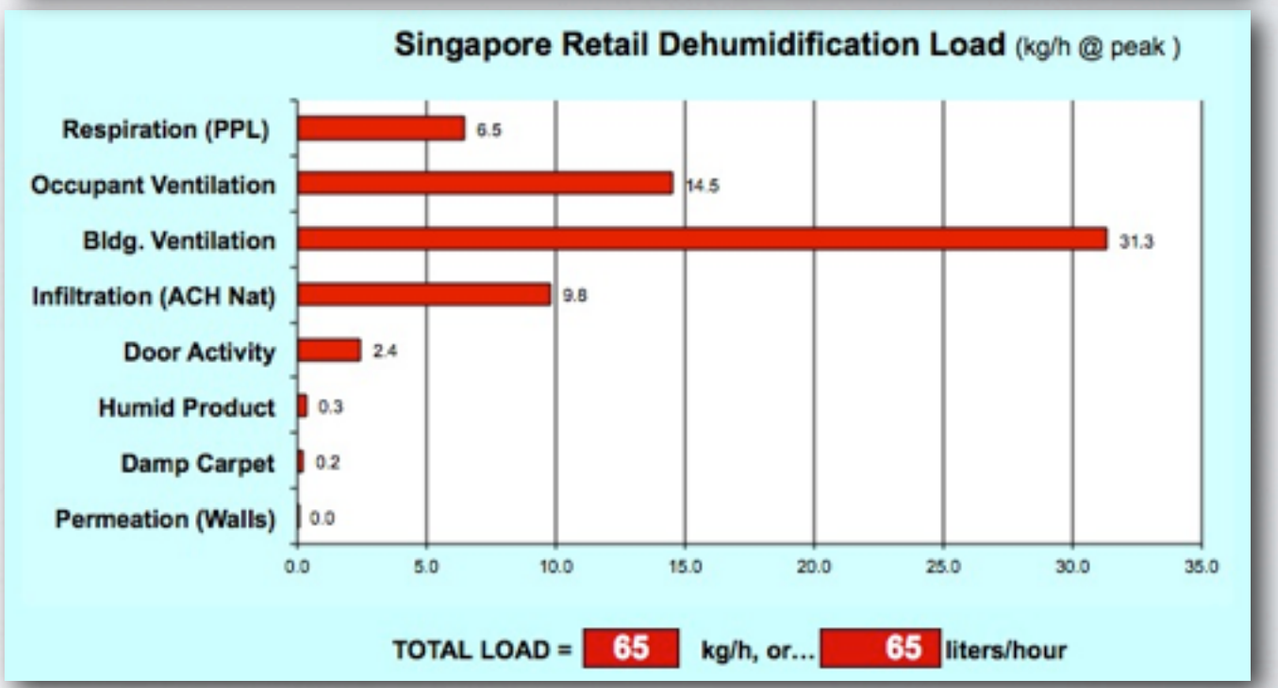


# load at peak dry bulb vs. peak dew point

**47** kg/h at peak Dry Bulb



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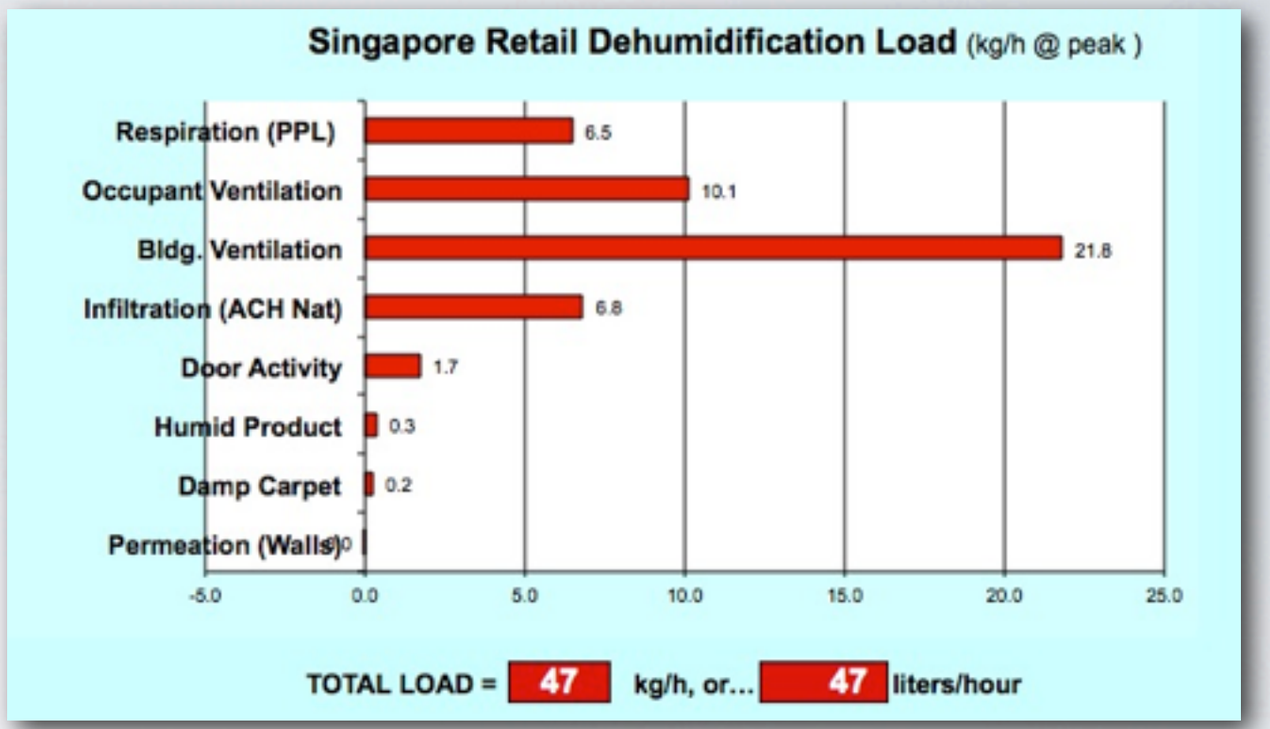
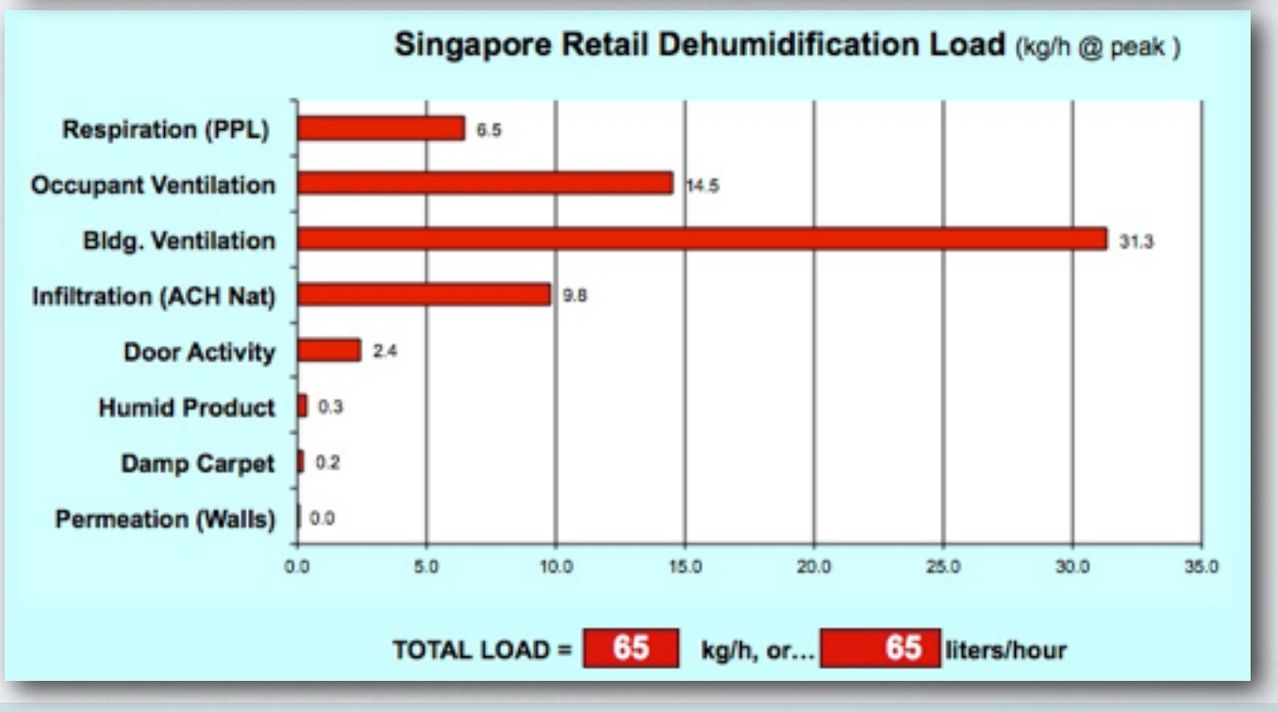
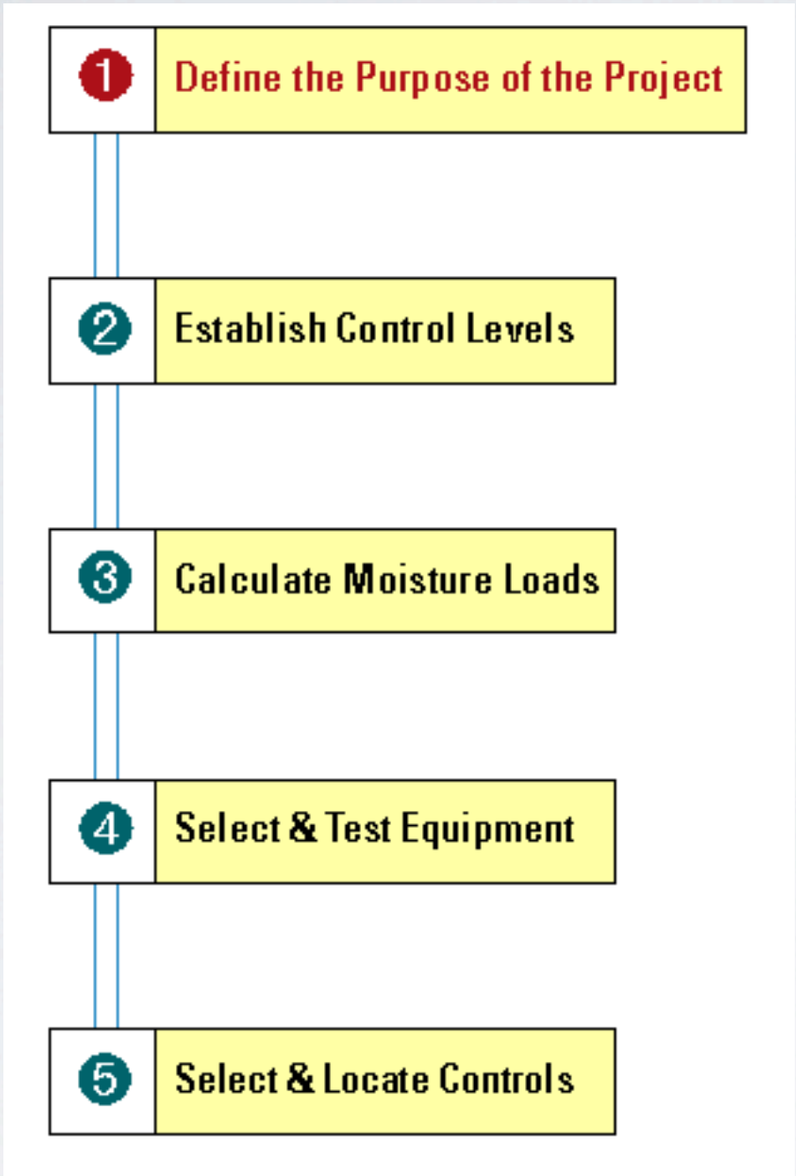



**65** kg/h at peak Dew Point



# Step 4 - Size and select the dehumidifier



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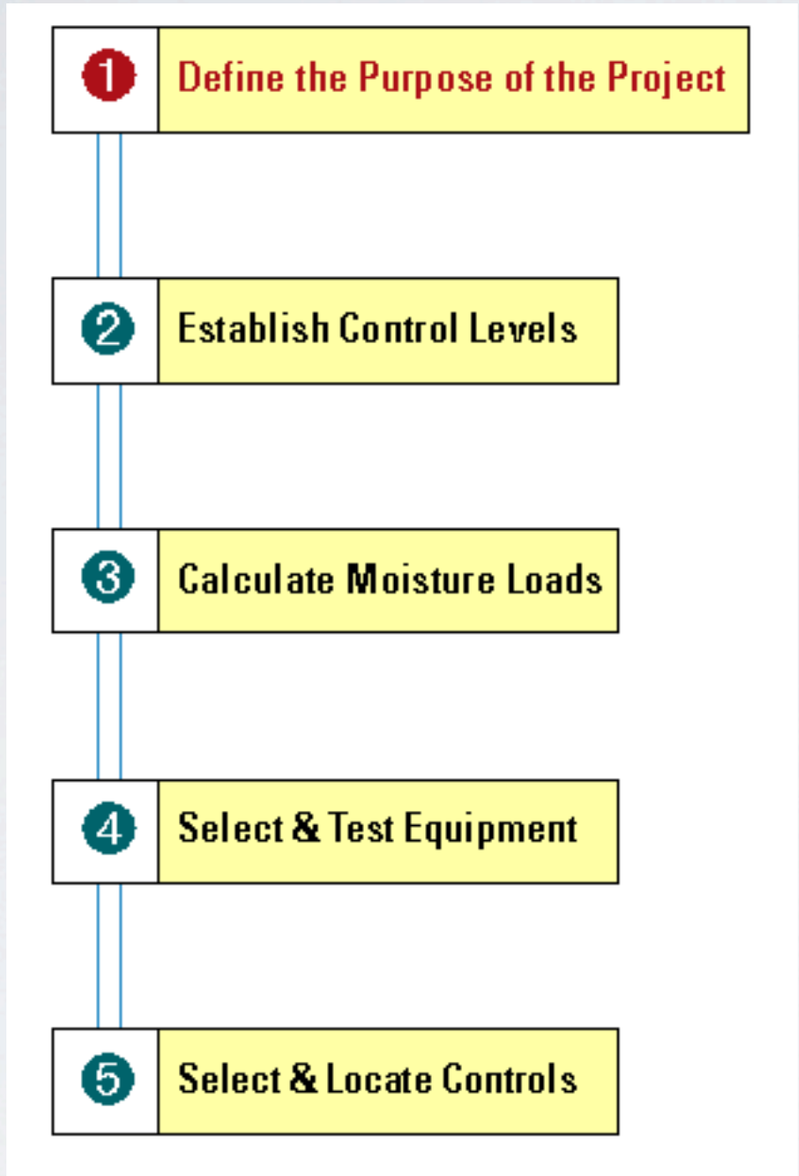
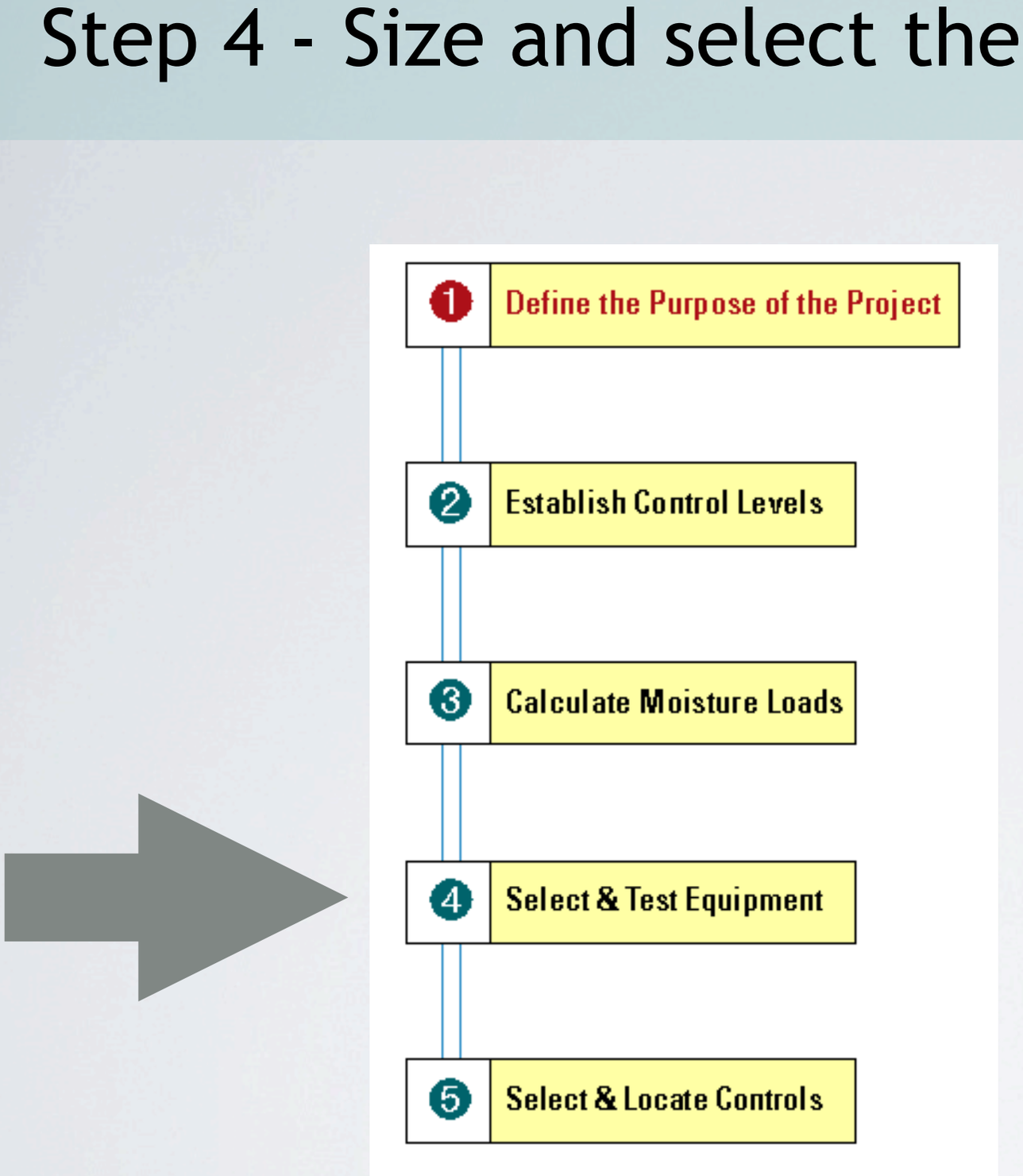



## Cool-Reheat Dehumidifier



# Step 4 - Size and select the dehumidifier



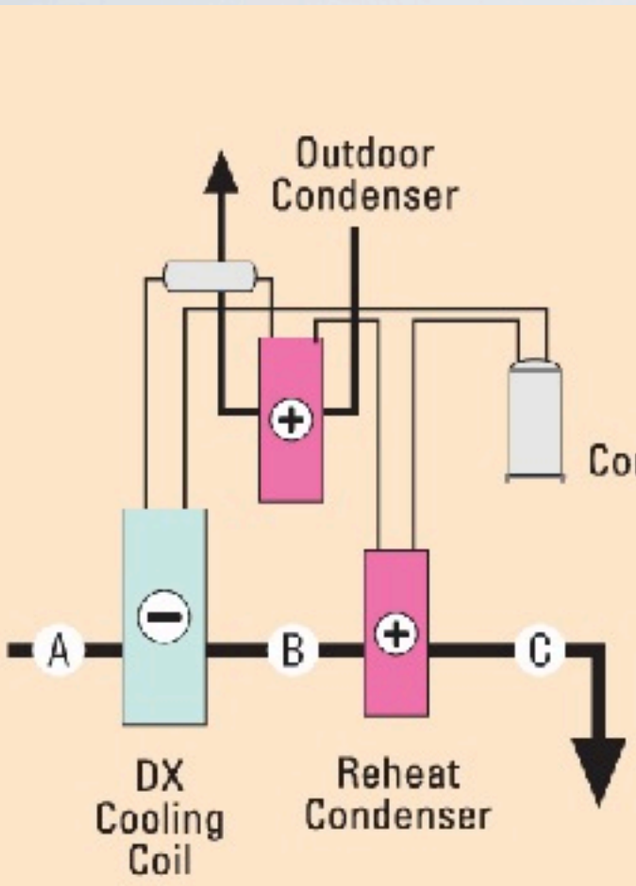

## Cool-Reheat Dehumidifier



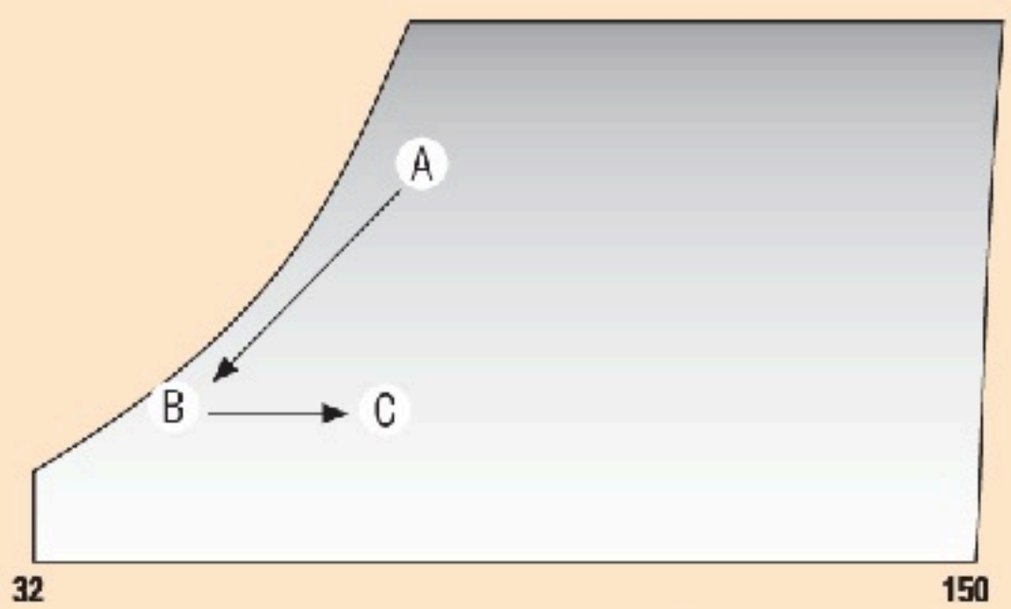
## Desiccant Dehumidifier



# Cool-Reheat Dehumidifier

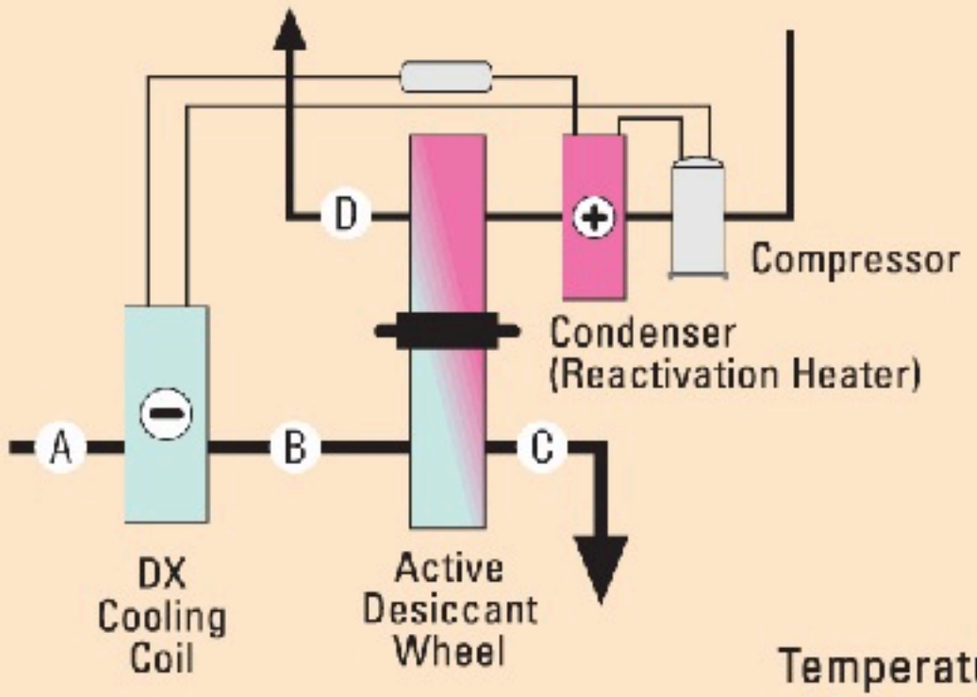



**Mechanical Dehumidifier Using Condenser Reheat**

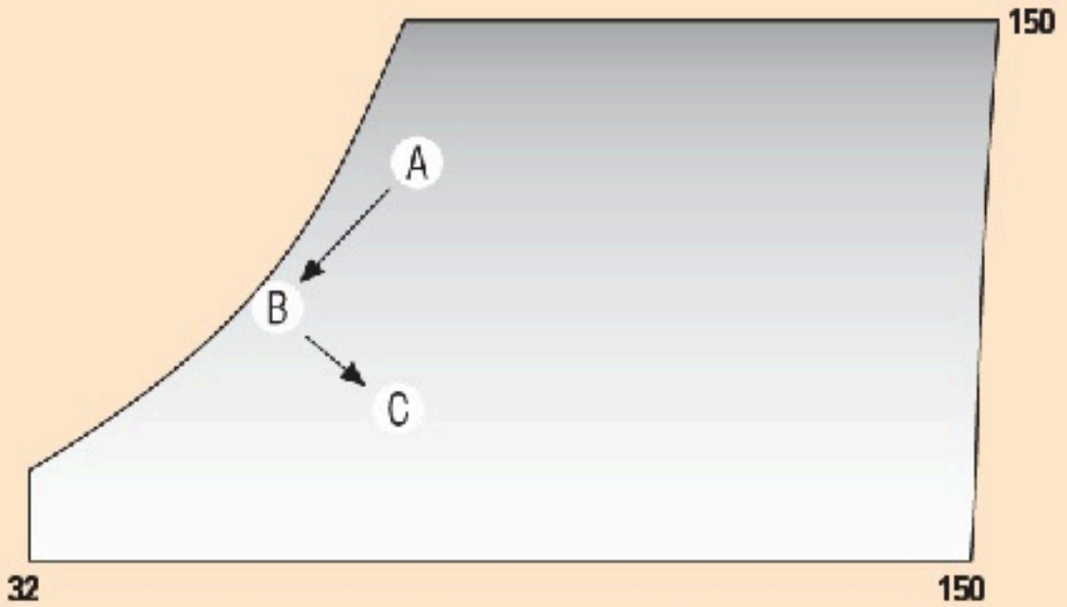



| | A | B | C |
|---|---|---|---|
| Temperature (°F) | 80 | 50 | 75 |
| Moisture (gr/lb) | 124 | 54 | 54 |
| Air Flow (scfm) | 2,000 | 2,000 | 2,000 |
| (°C) | 26.7 | 10.0 | 23.9 |
| (g/kg) | 17.7 | 7.7 | 7.7 |
| (l/s) | 942 | 942 | 942 |

# Desiccant Dehumidifier




**Desiccant Dehumidifier**
**Using Condenser Heat Reactivation**




| | A | B | C | D |
|---|---|---|---|---|
| Temperature (°F) | 80 | 60 | 77 | 98 |
| Moisture (gr/lb) | 124 | 77 | 54 | 144 |
| Air Flow (scfm) | 2,000 | 2,000 | 2,000 | 2,000 |
| (°C) | 26.7 | 16.0 | 25.0 | 37.0 |
| (g/kg) | 17.7 | 11.0 | 7.7 | 20.6 |
| (l/s) | 942 | 942 | 942 | 942 |

# Measuring Dehumidification

How to measure?

**Humidity ratios (gr/lb or g/kg) before and after the dehumidifier**

# Measuring Dehumidification



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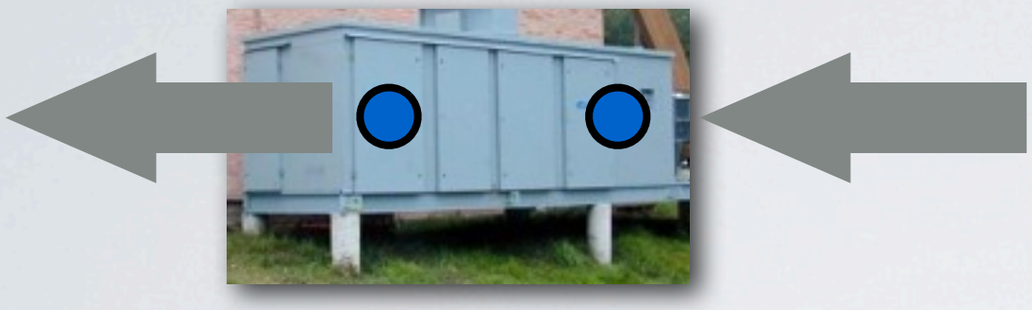

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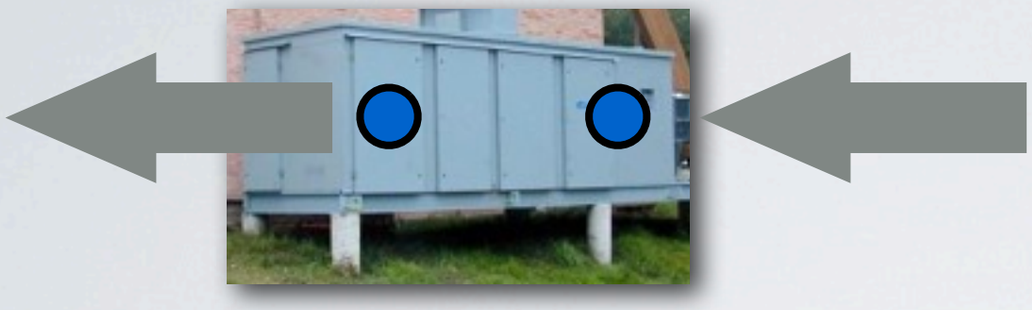

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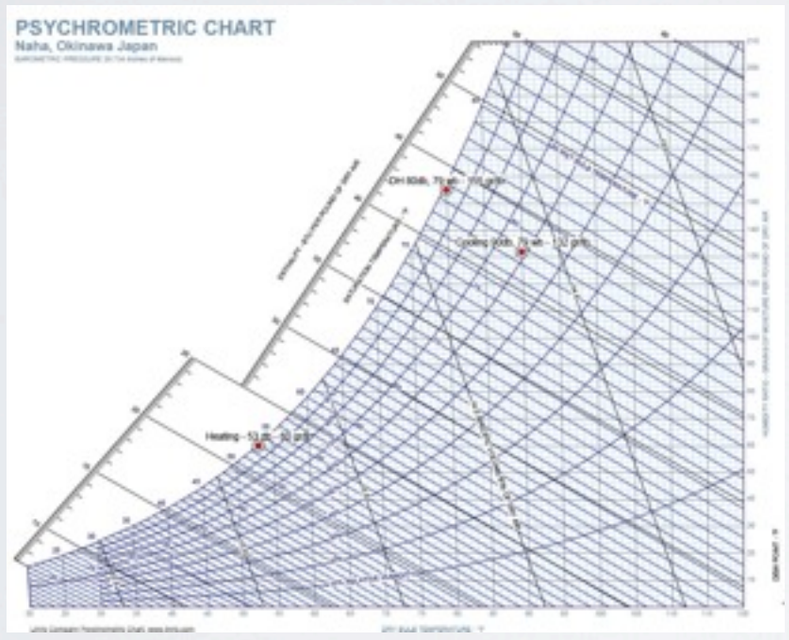

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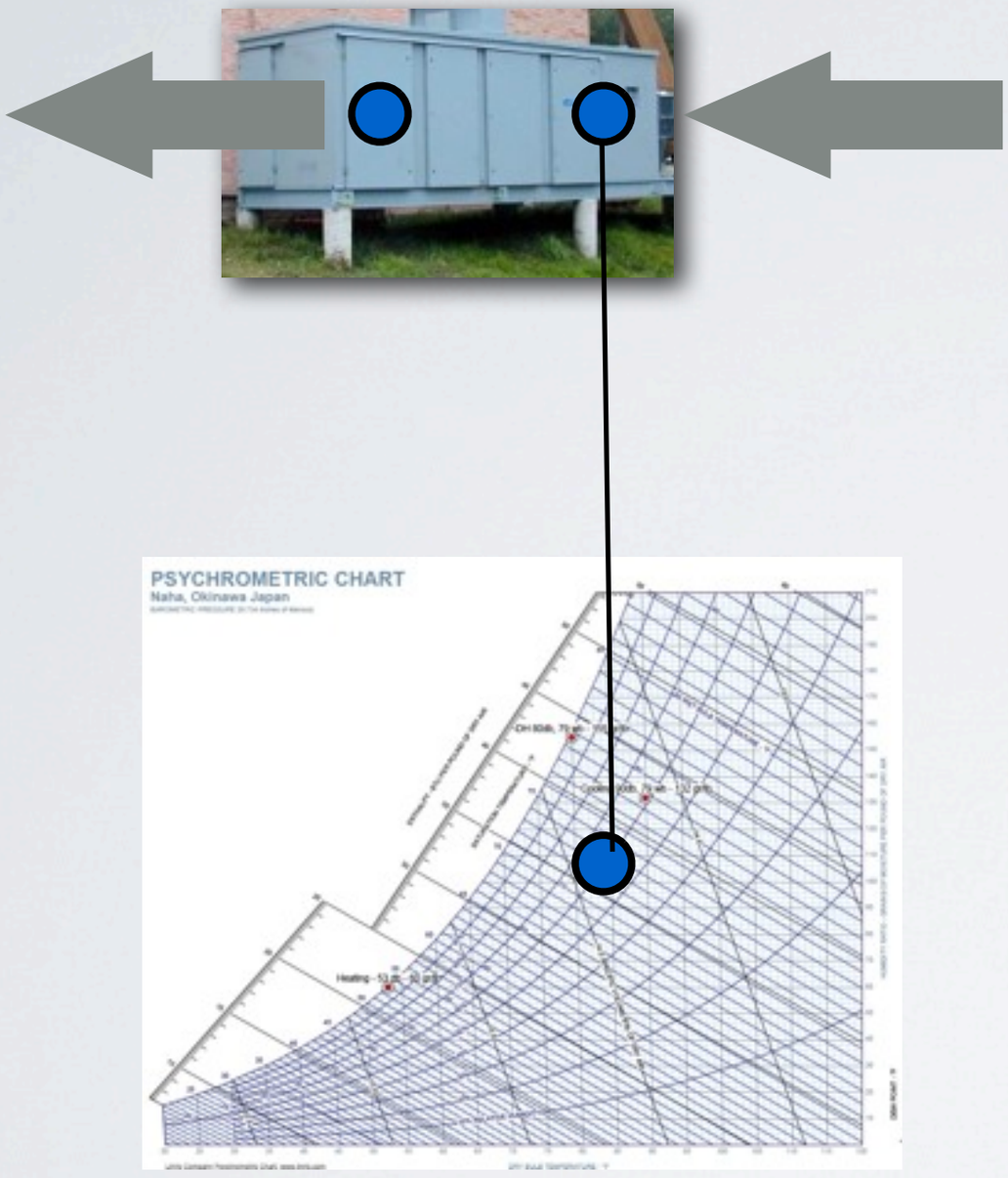


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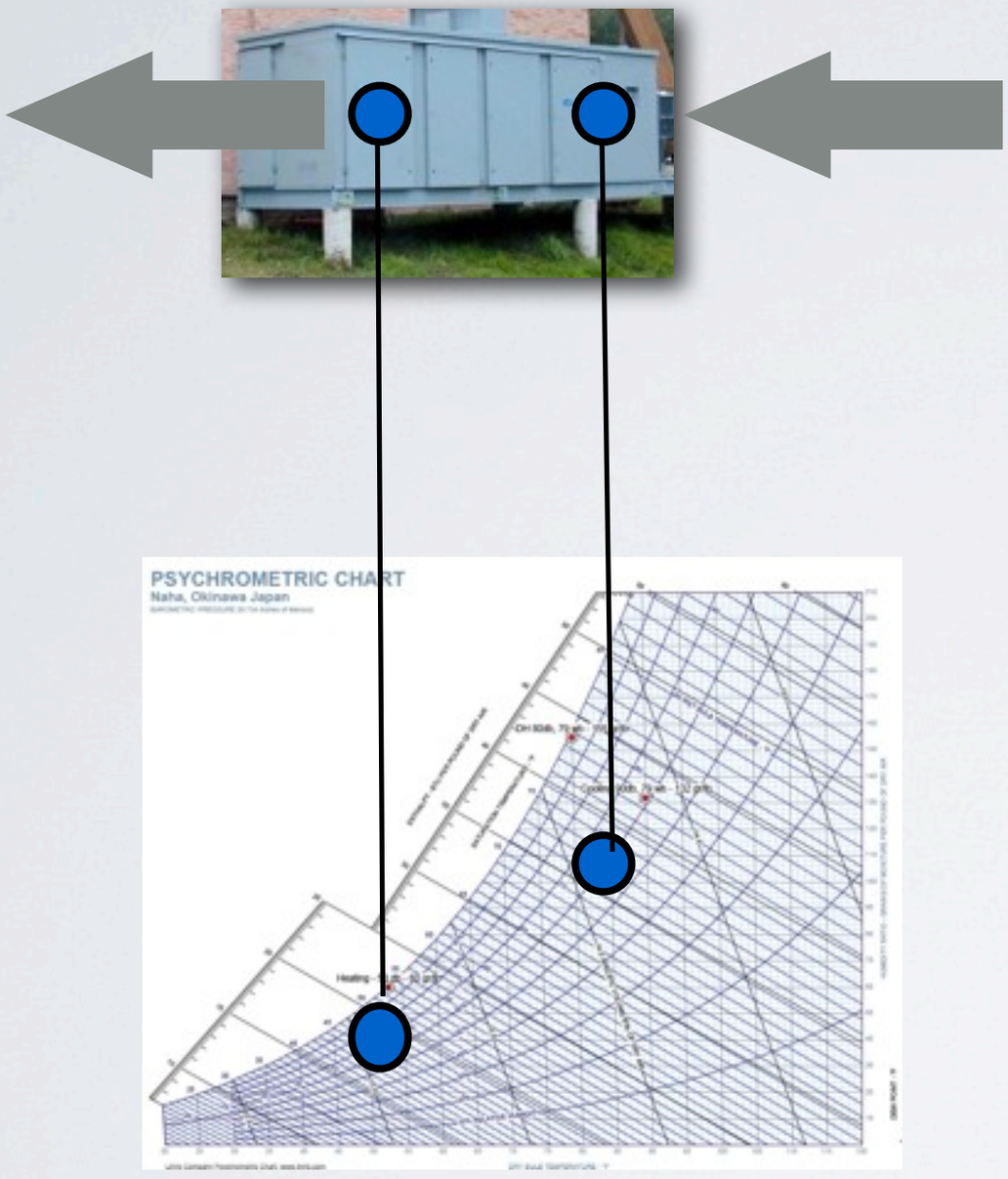


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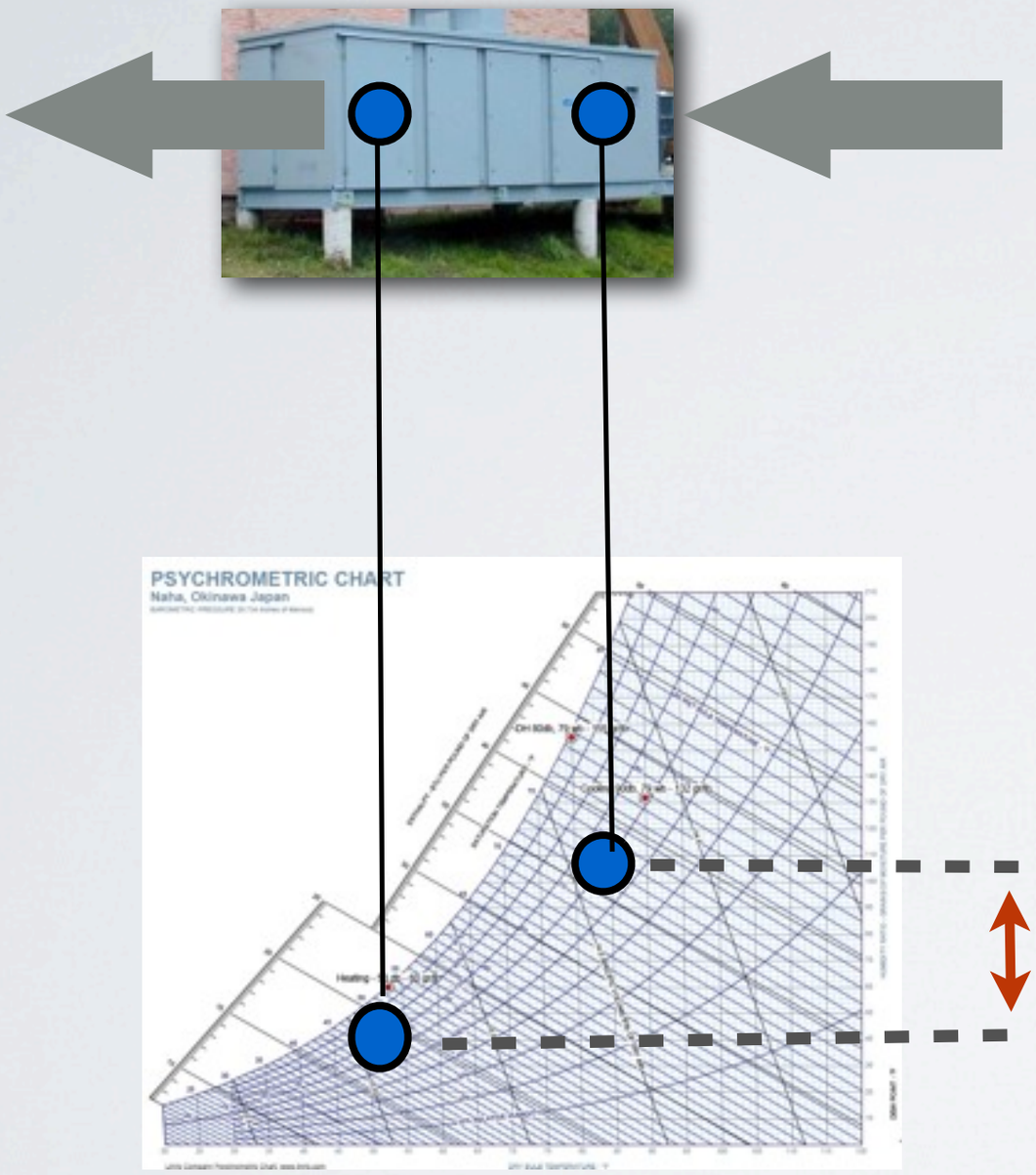


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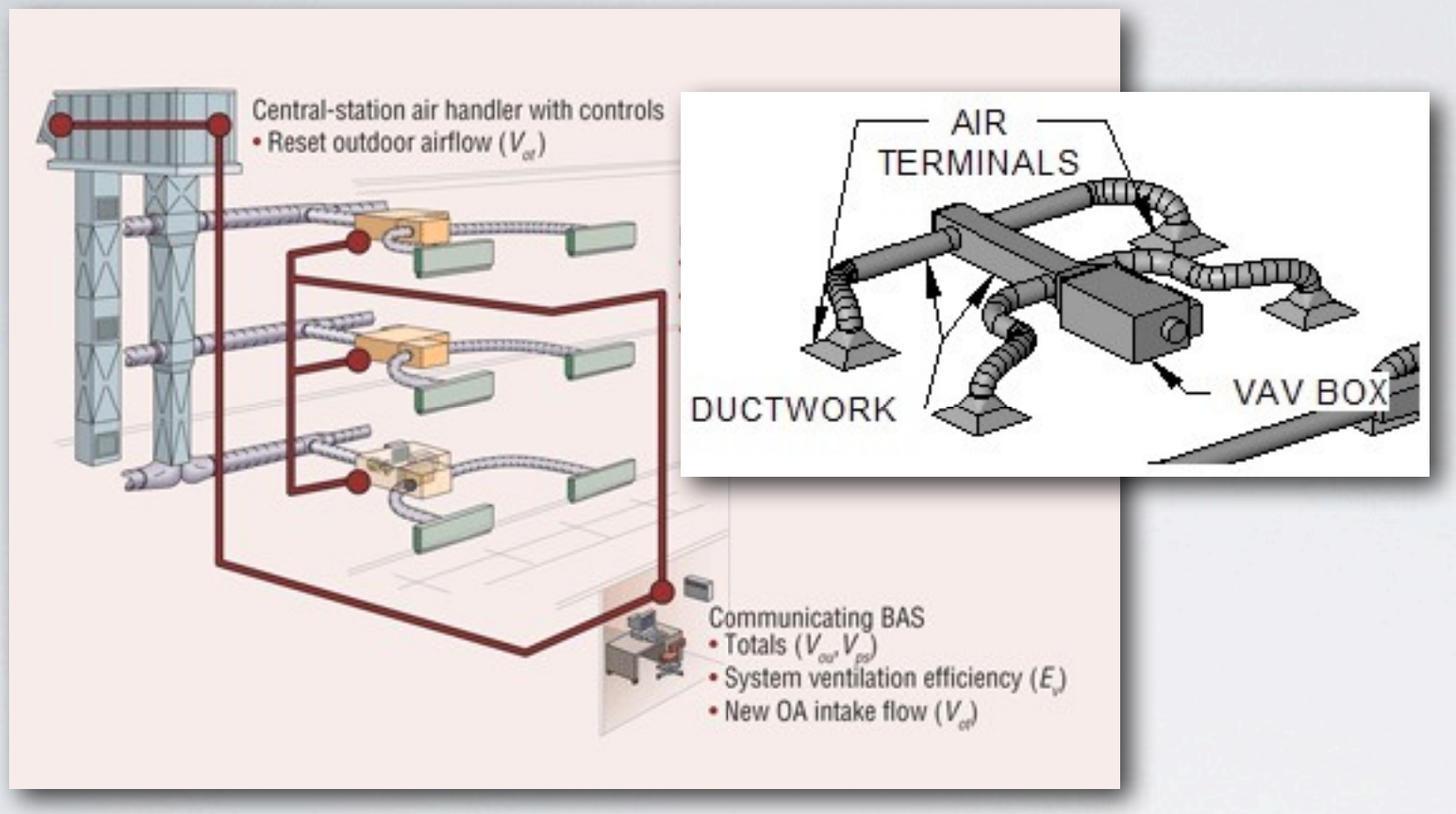

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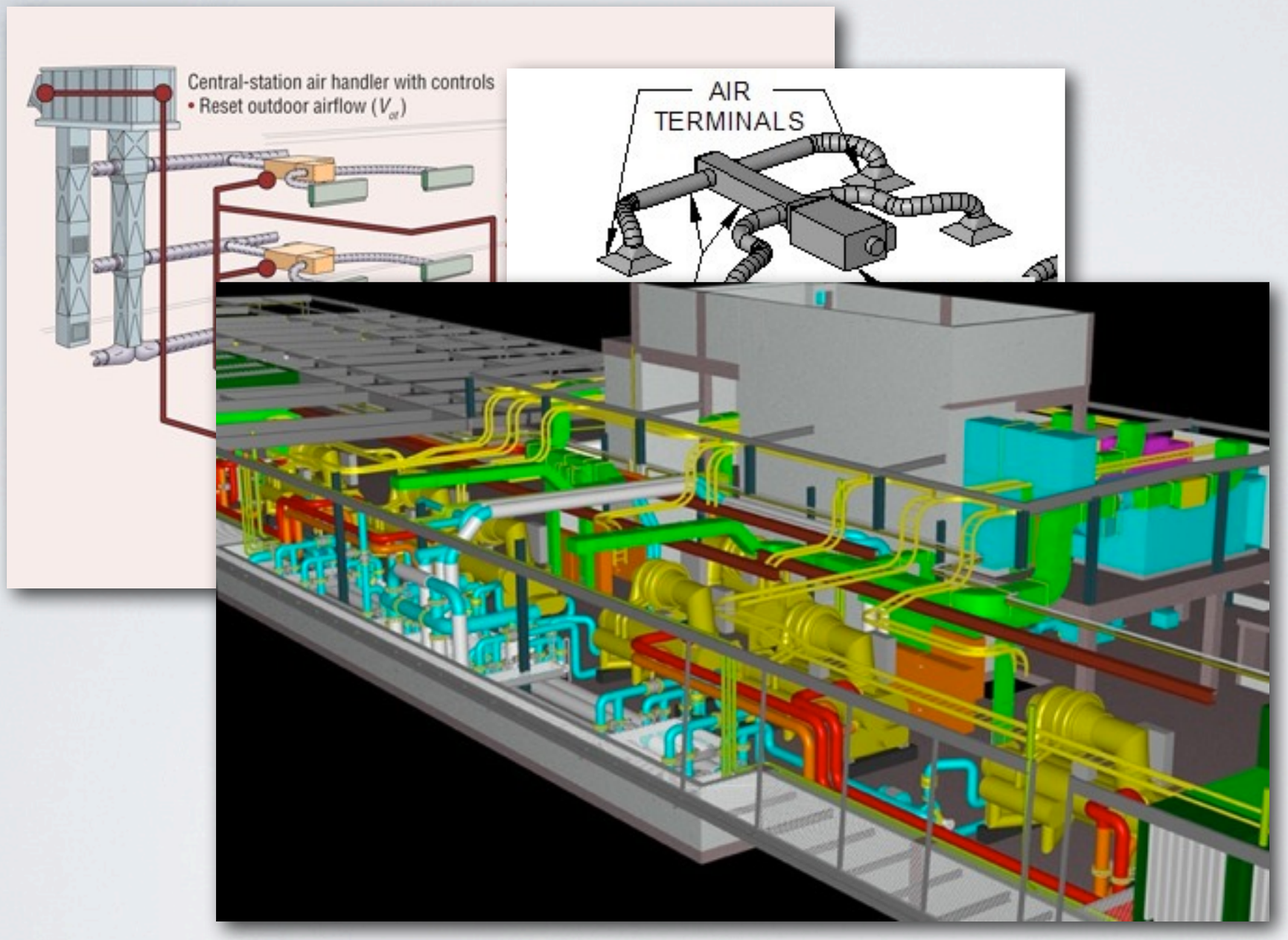

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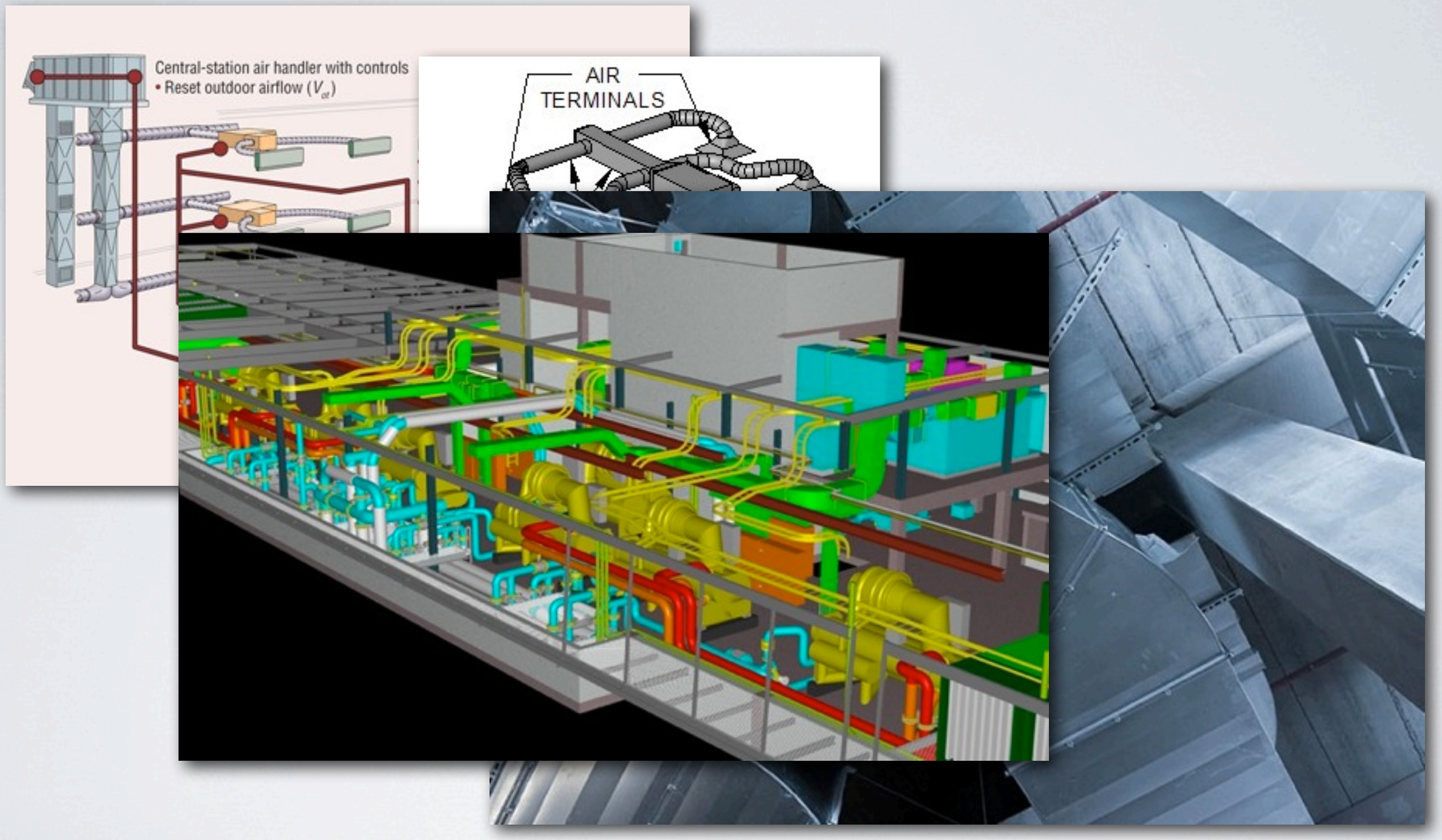

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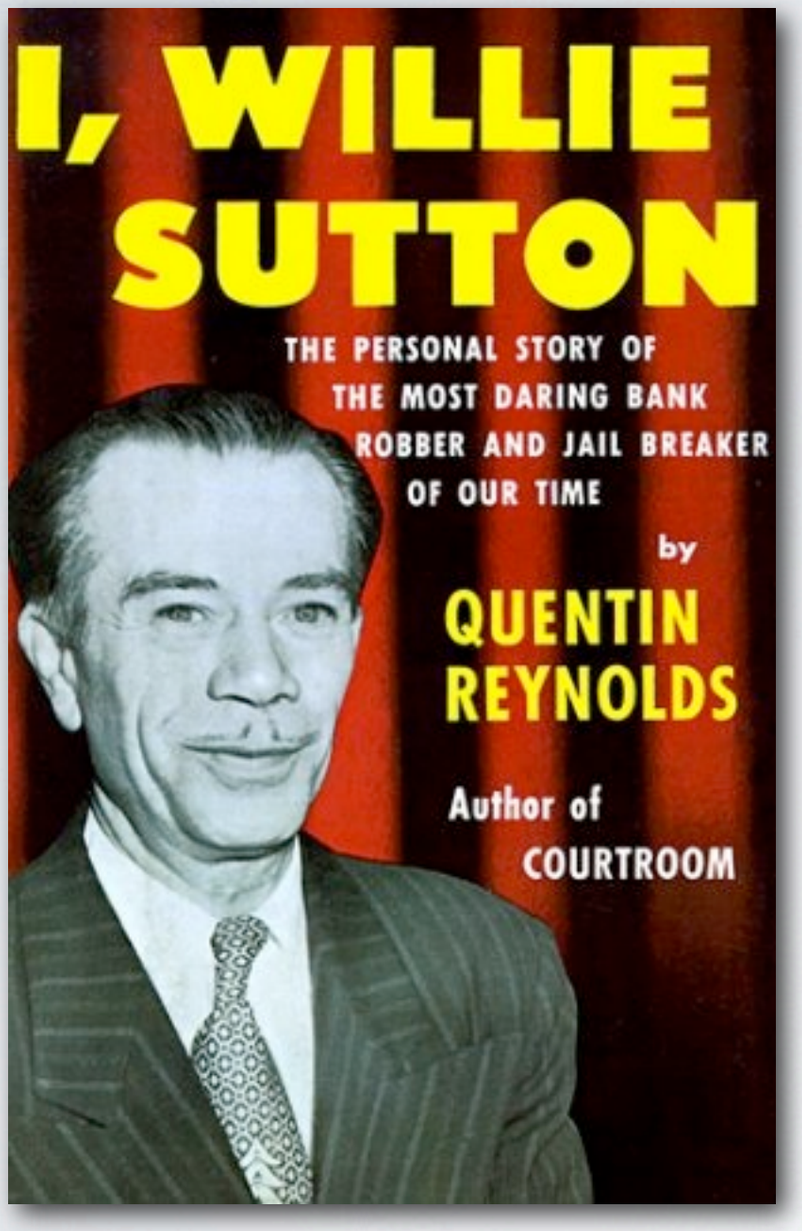

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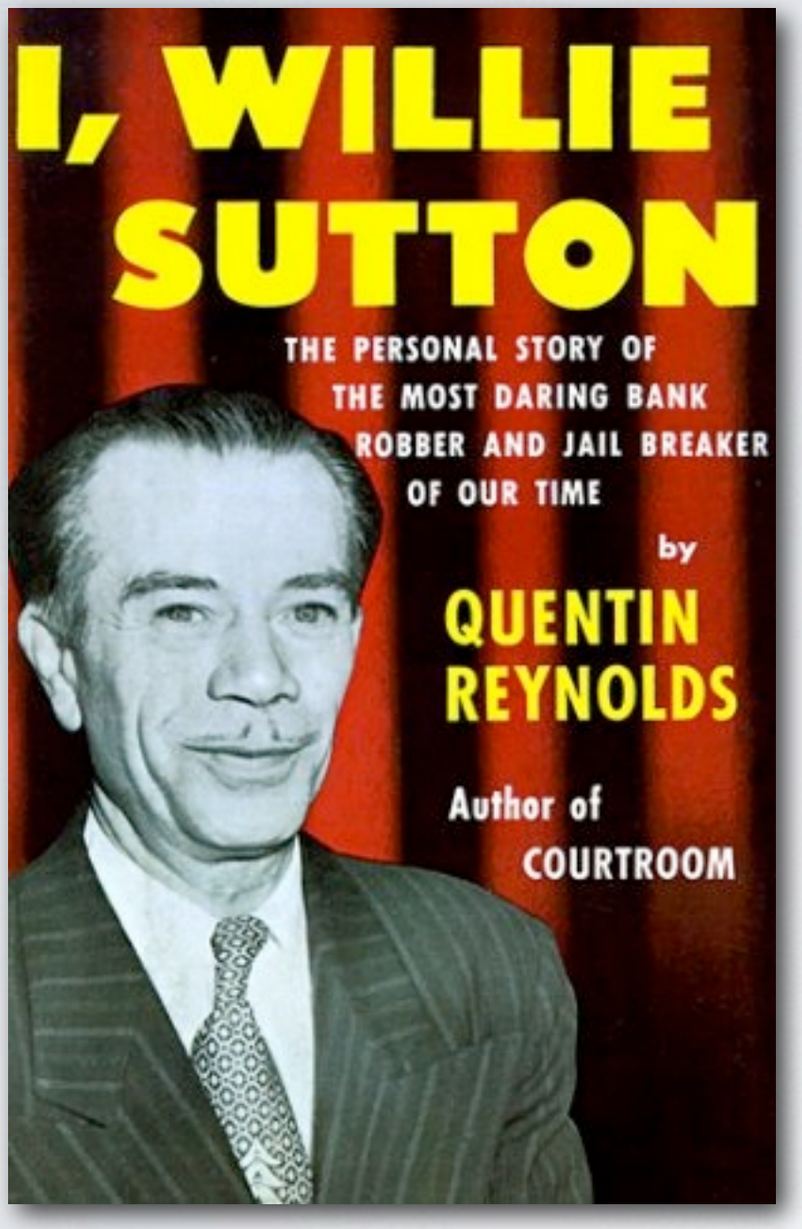


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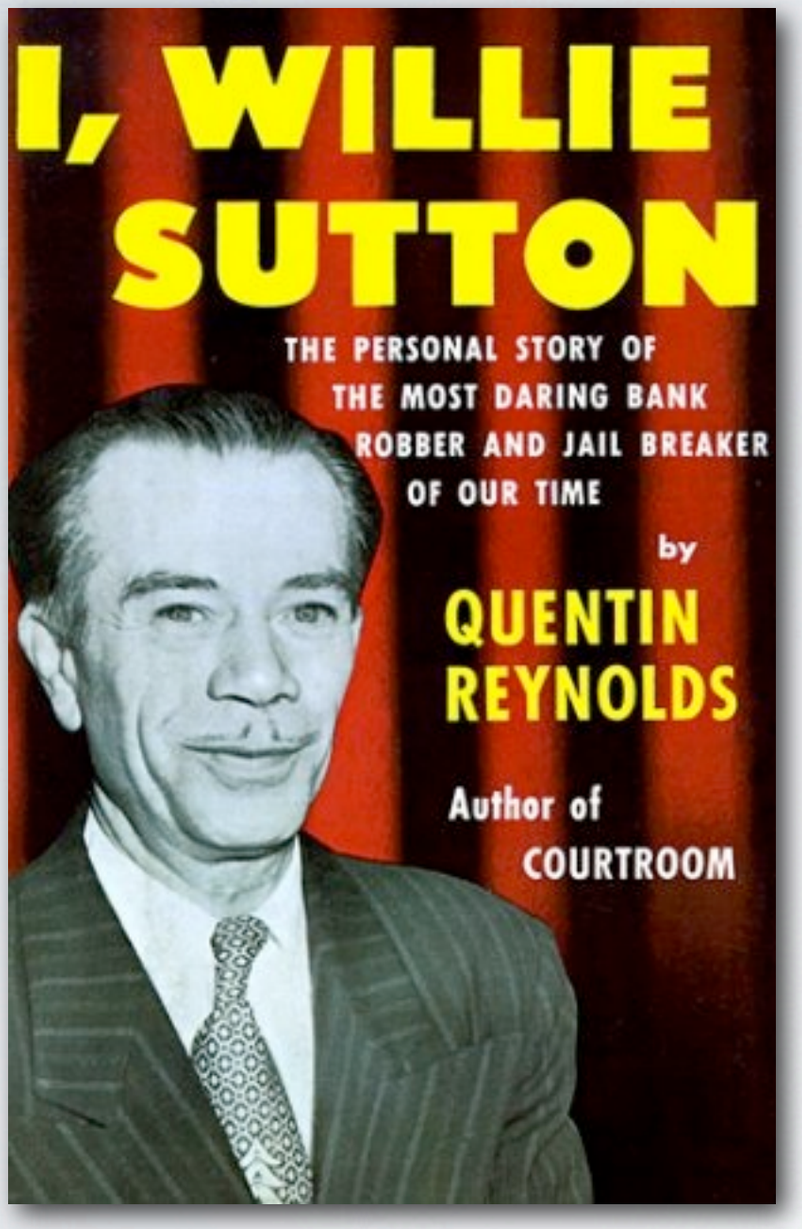


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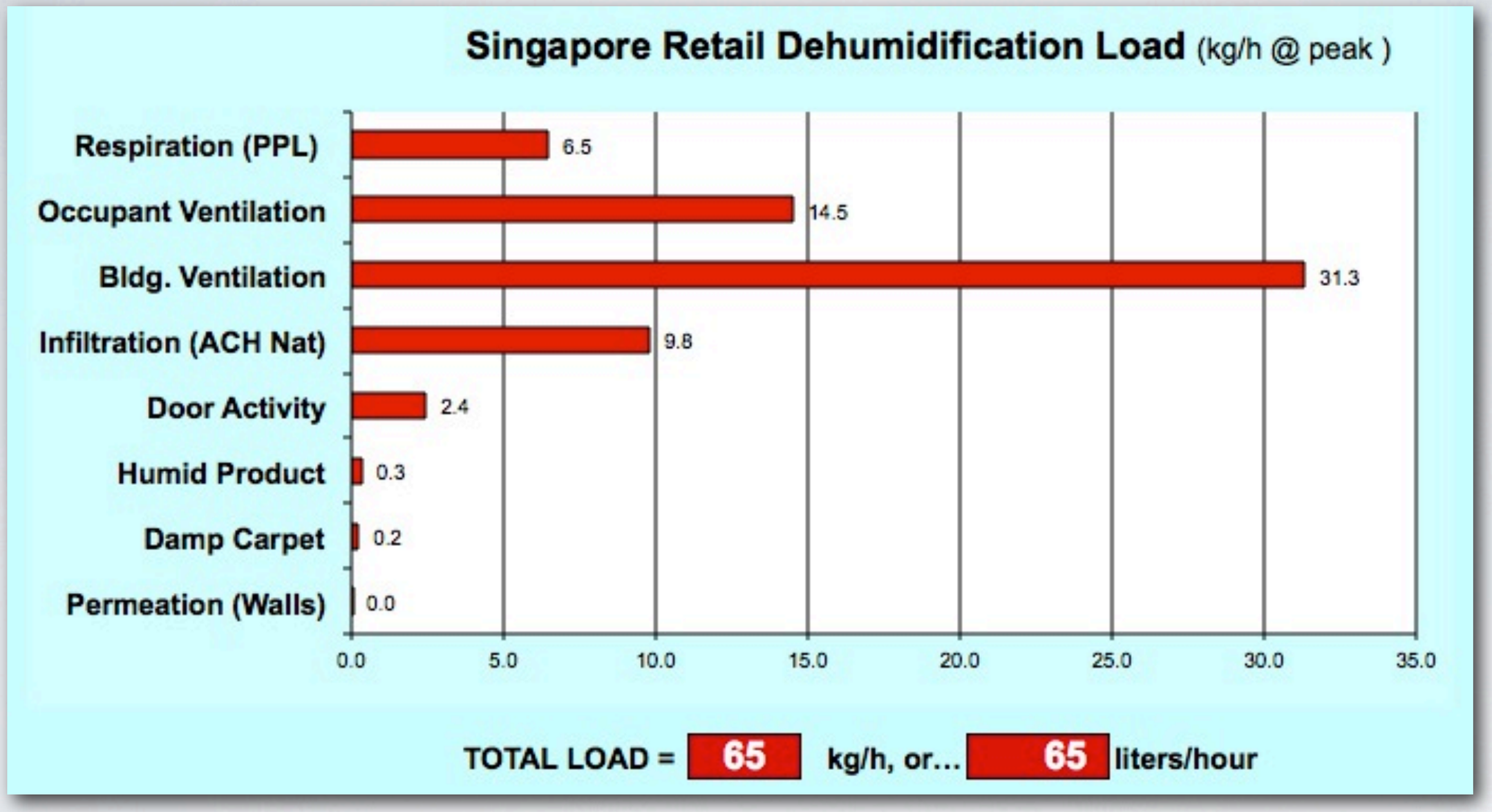

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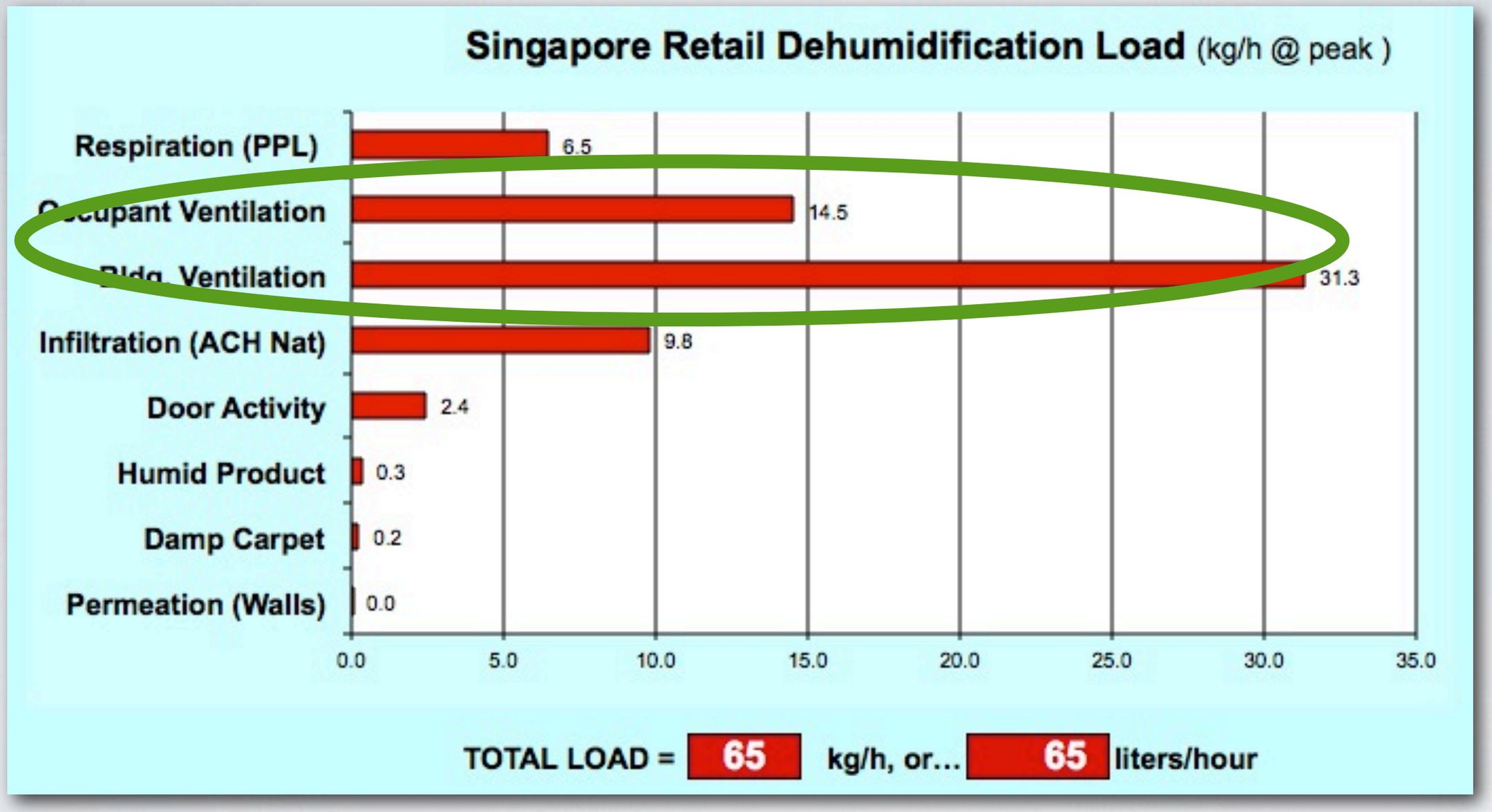

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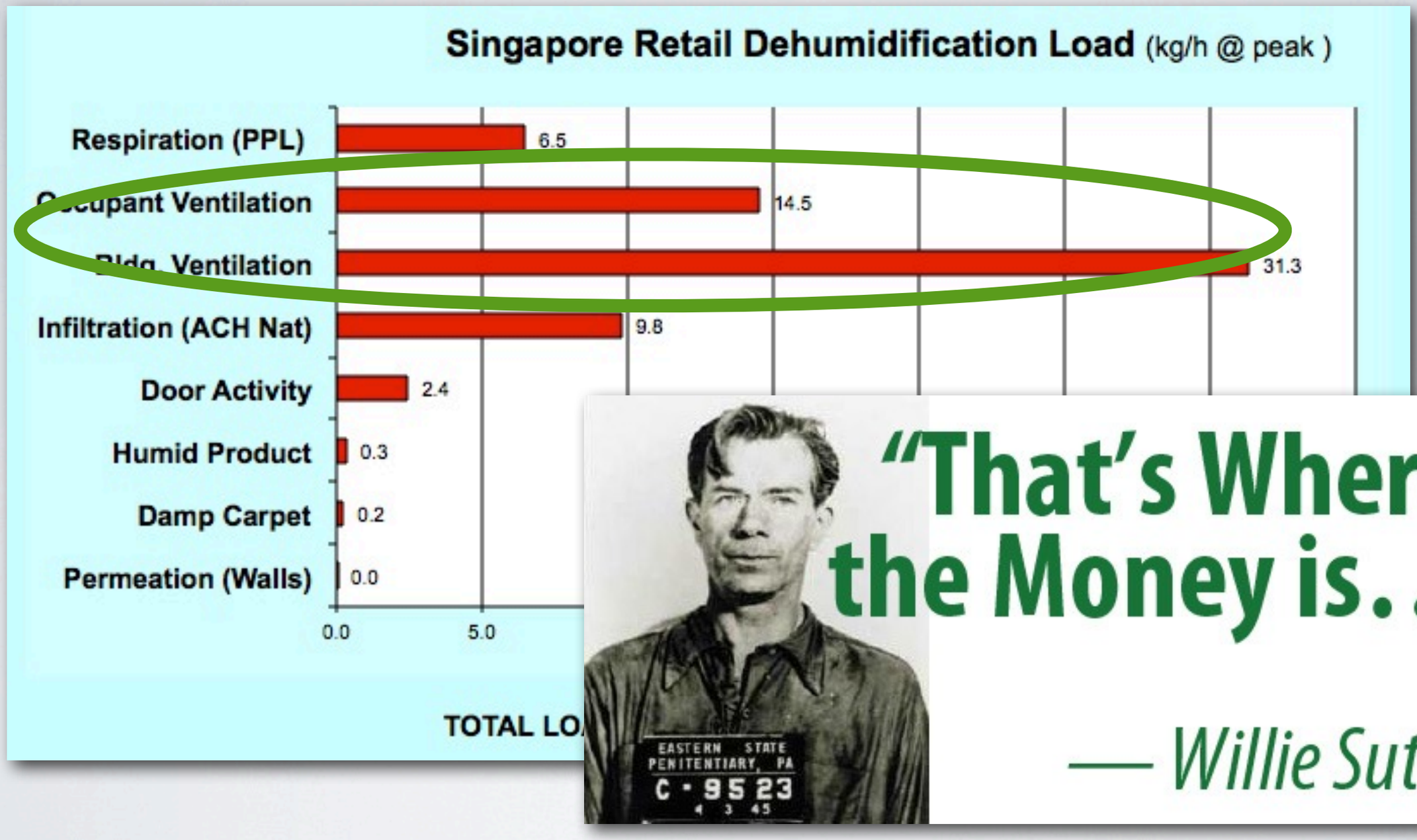
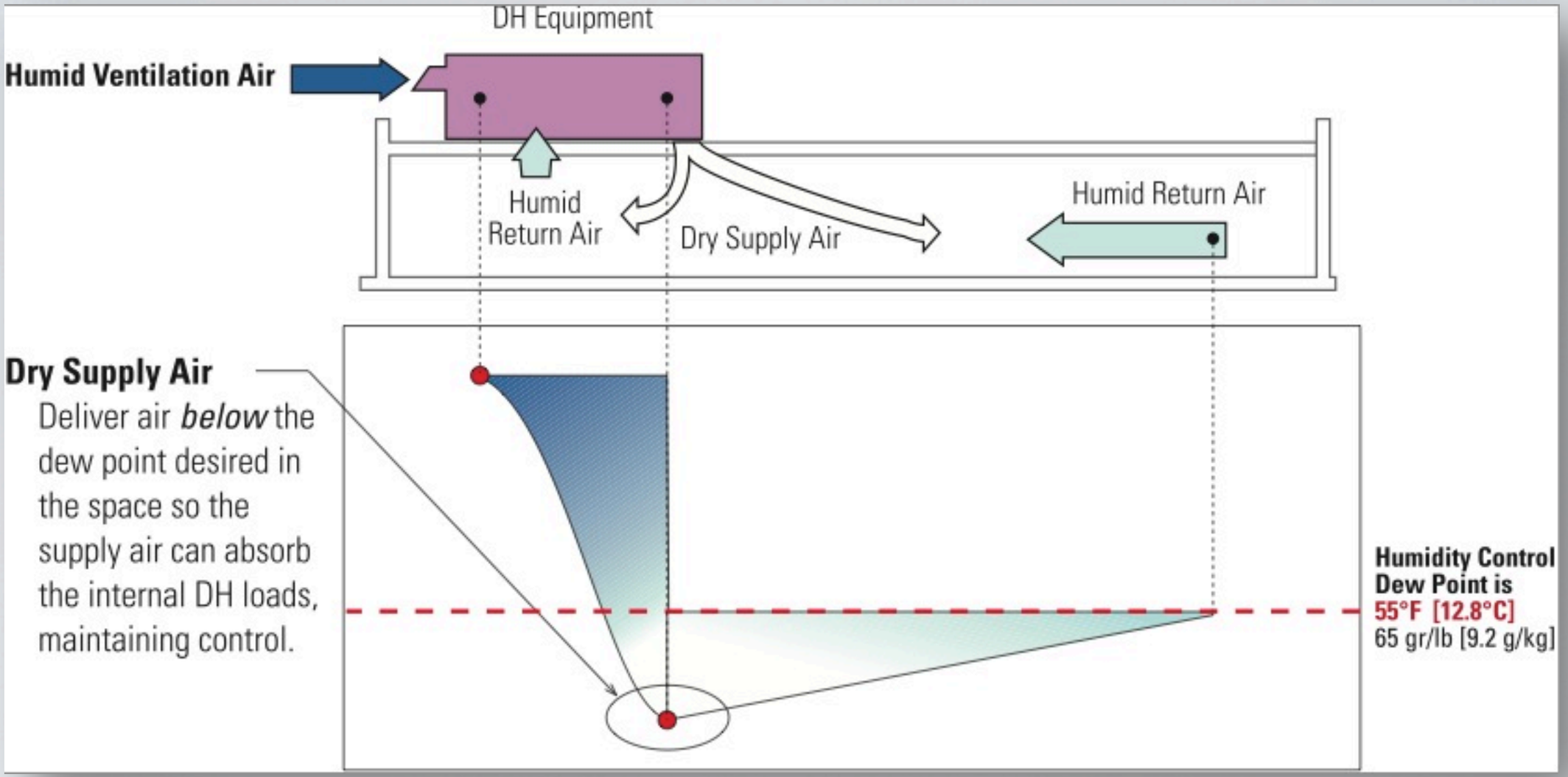
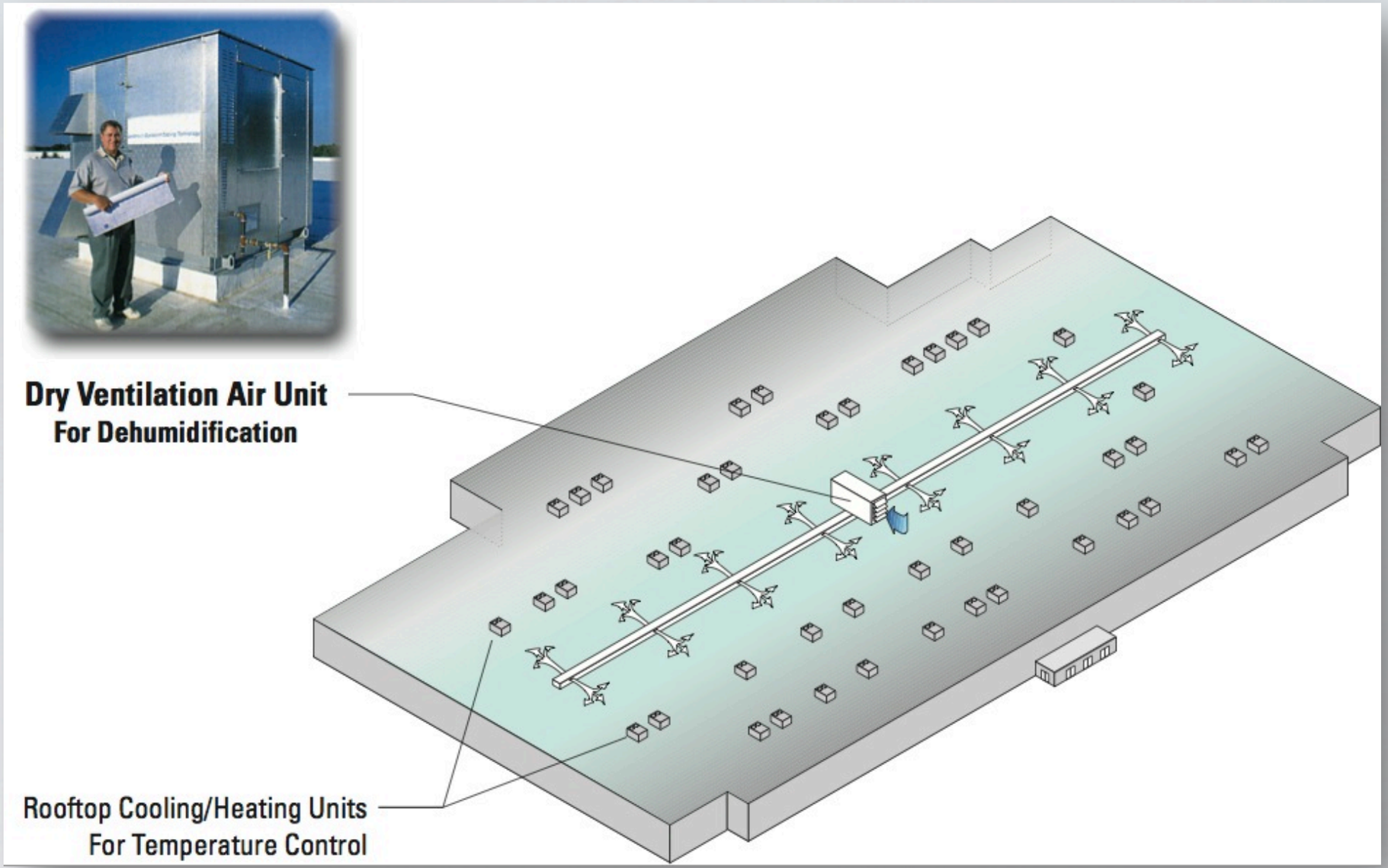


# Dry where the load is - DOAS controls humidity




Source: ASHRAE Humidity Control Design Guide - 2006

# Typical layout - Big box retail

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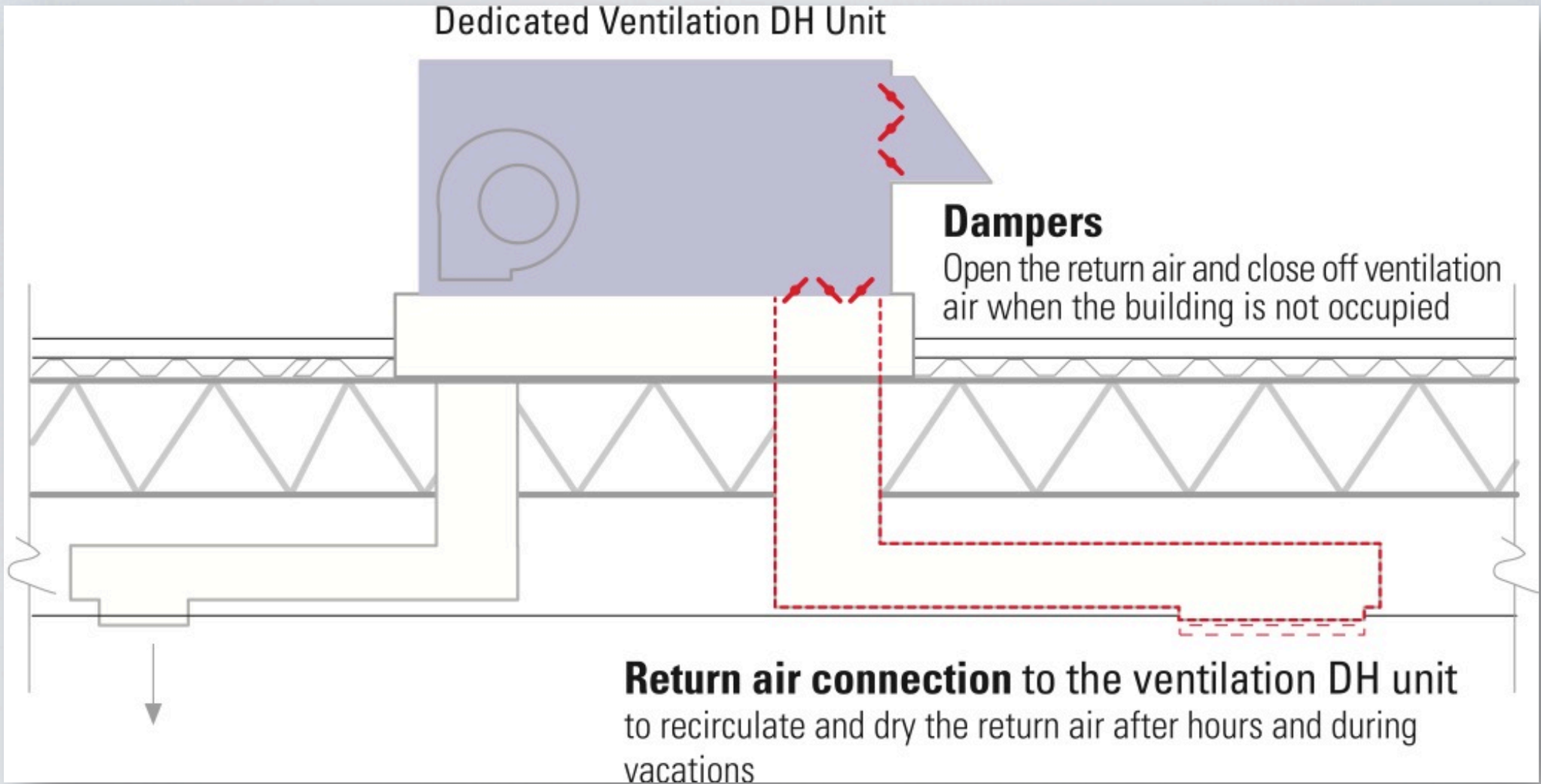
# Add return air connection for humidity control during unoccupied hours and vacations

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## Section 2b

# Common HVAC Design Shortcomings

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  - Long term - REPLACE large central exhaust systems with many small, locally-controlled exhaust and supply systems equipped with energy recovery devices

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**Measured Ventilation Air Flow - 510 Office Buildings**

ASHRAE Standard Requirement (At the time of measurement)
Excess ventilation

| | Per Person cfm/person [l/s/person] | Per Unit Floor Area cfm/ft2 [l/s.m2] | Air Changes Per Hour |
|---|---|---|---|
| Mean (Average) | **117** [55] | 0.4 [2.04] | 2.00 |
| Median (Most Common) | **63** [30] | 0.2 [1.03] | 0.98 |
| Standard Deviation | **158** [74] | 0.5 [2.54] | 2.45 |
| Std 62.1-1989 | **20 [9]** | 0.07 [0.36] | 0.34 |

Andrew Persily (NIST) "Ventilation demand and performance in U.S. office buildings" ASHRAE Journal

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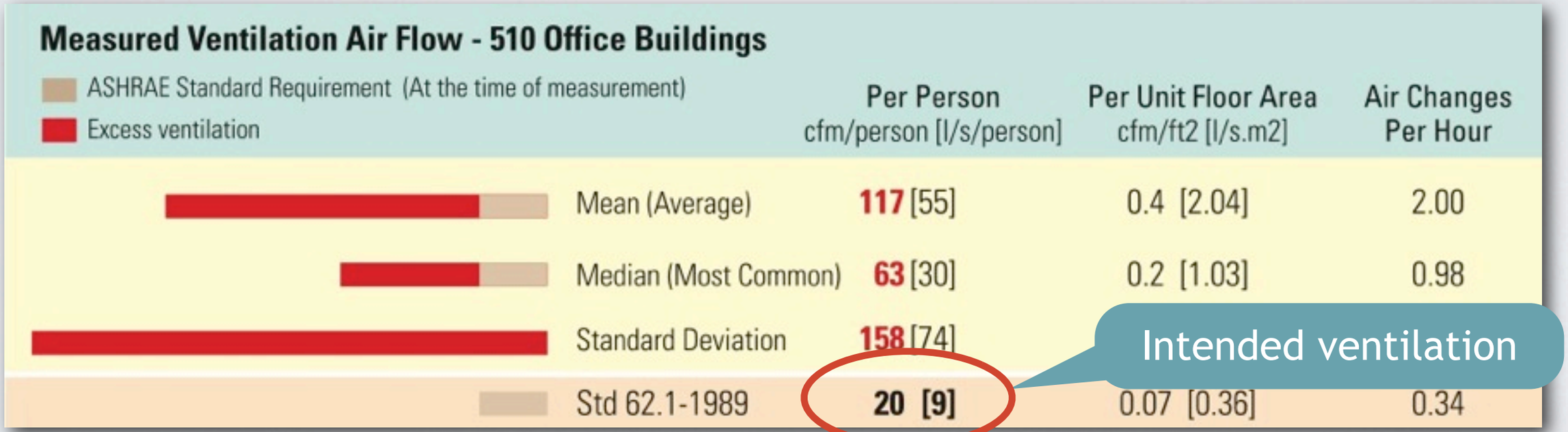


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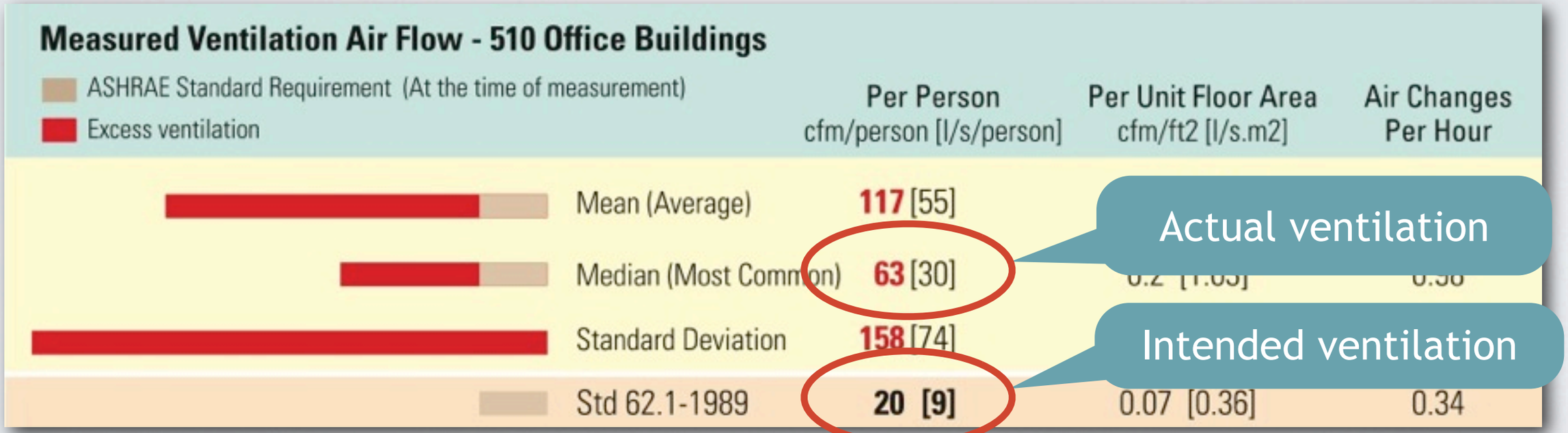


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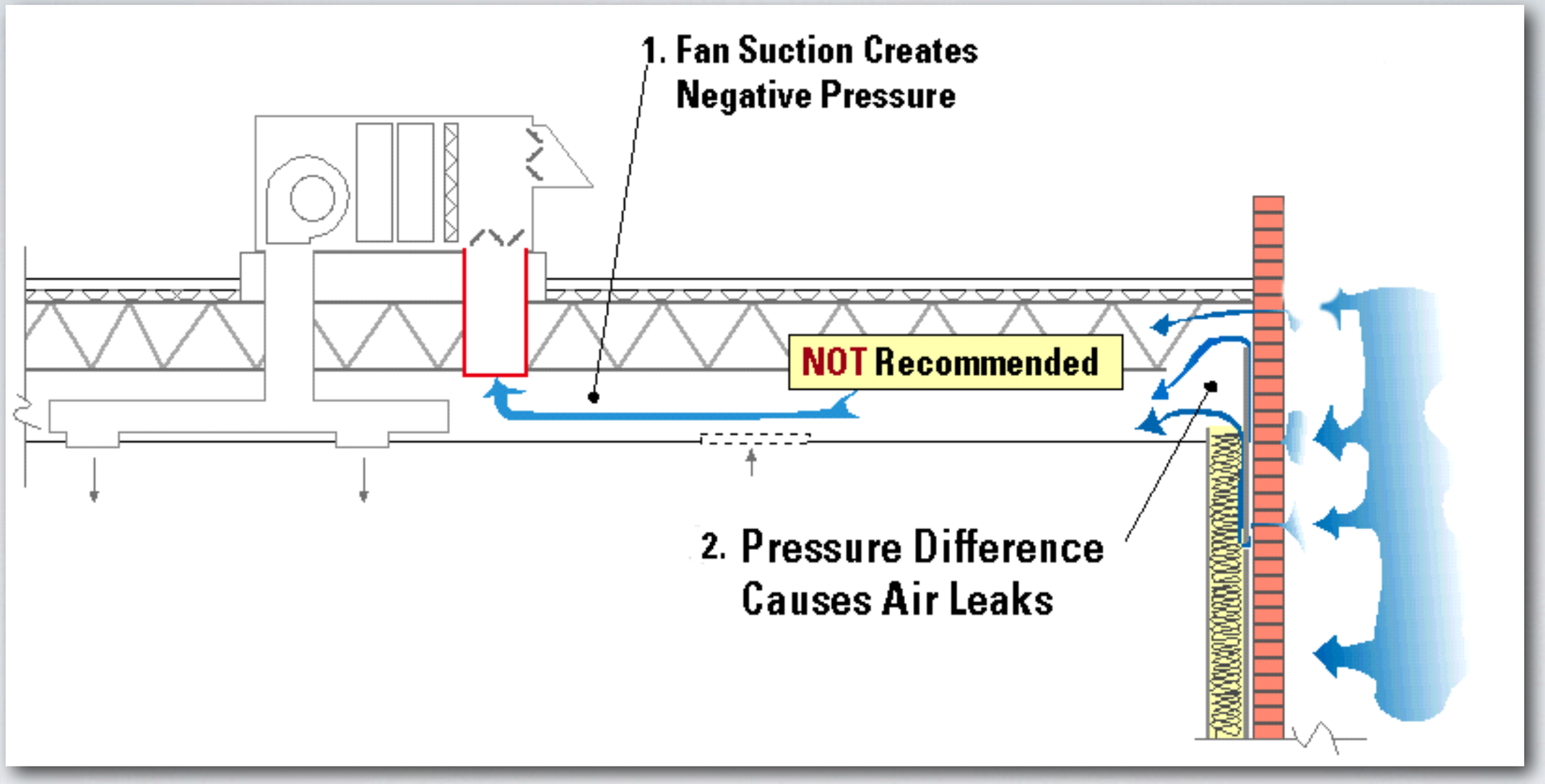
# Return plenums.. They leak a lot. It's a problem.



# Unsealed exhaust ducts pull humid air into the building from outdoors

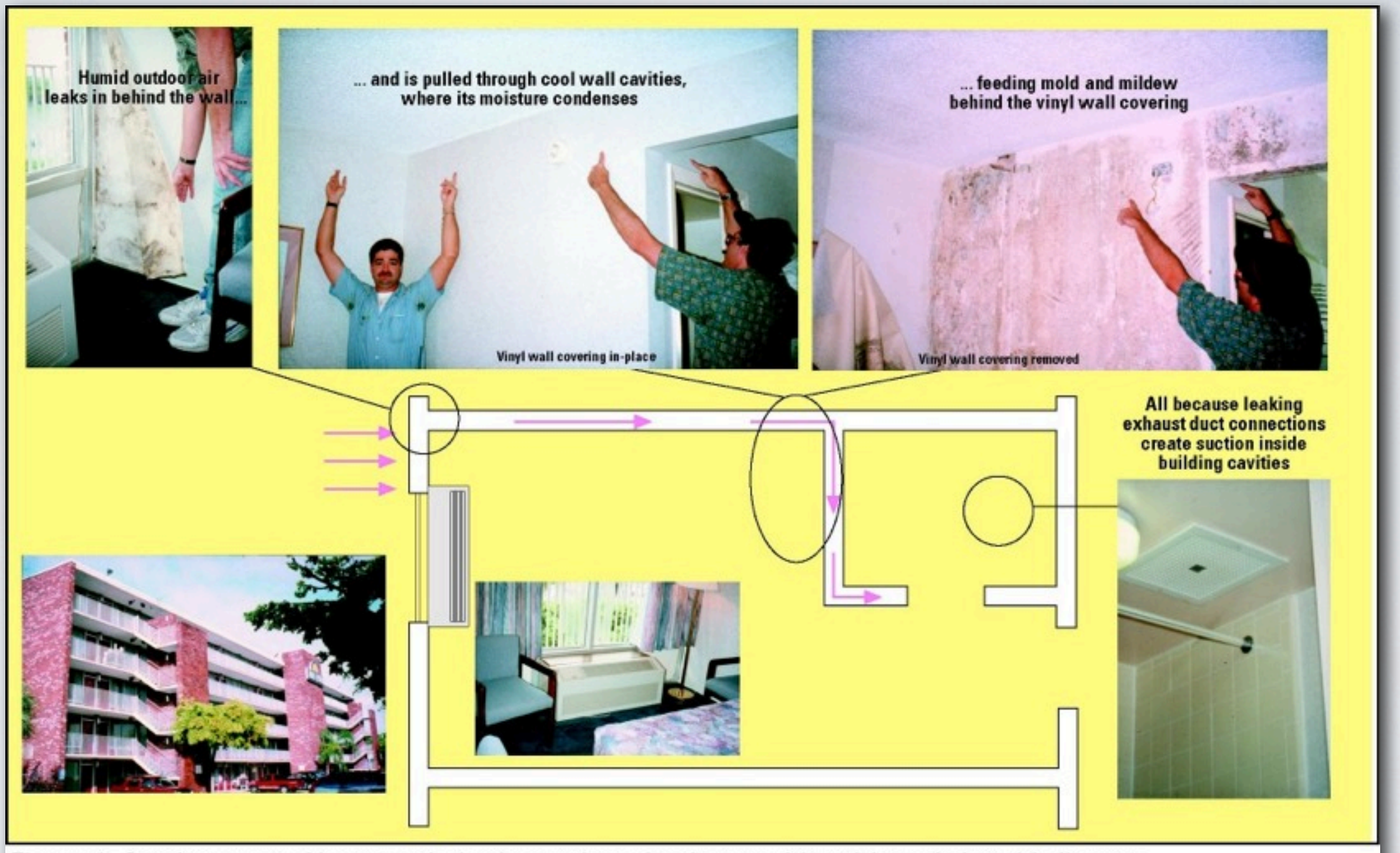
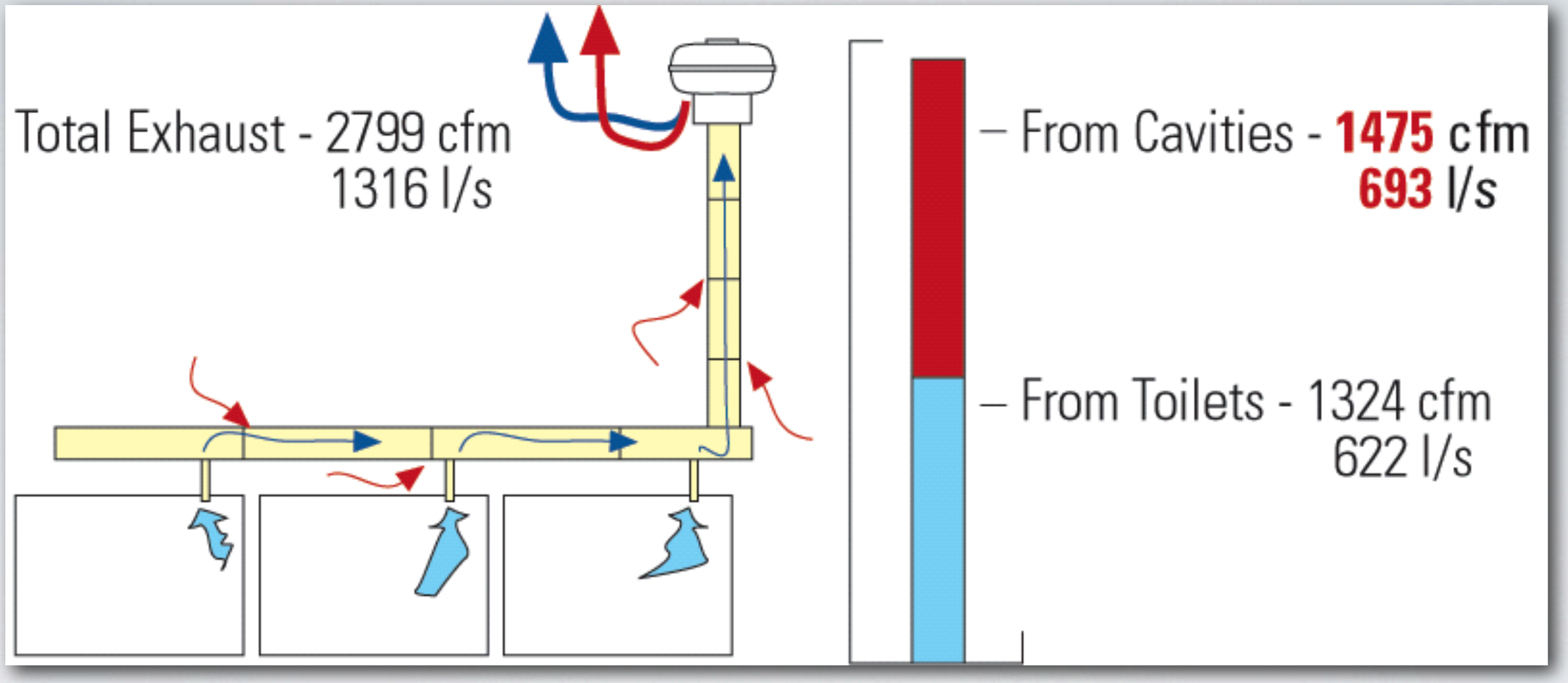



Figure 1: Suction created by unsealed exhaust ducts leads to mold problems in humid climates.

# How MUCH leakage from unsealed exhaust ducts?



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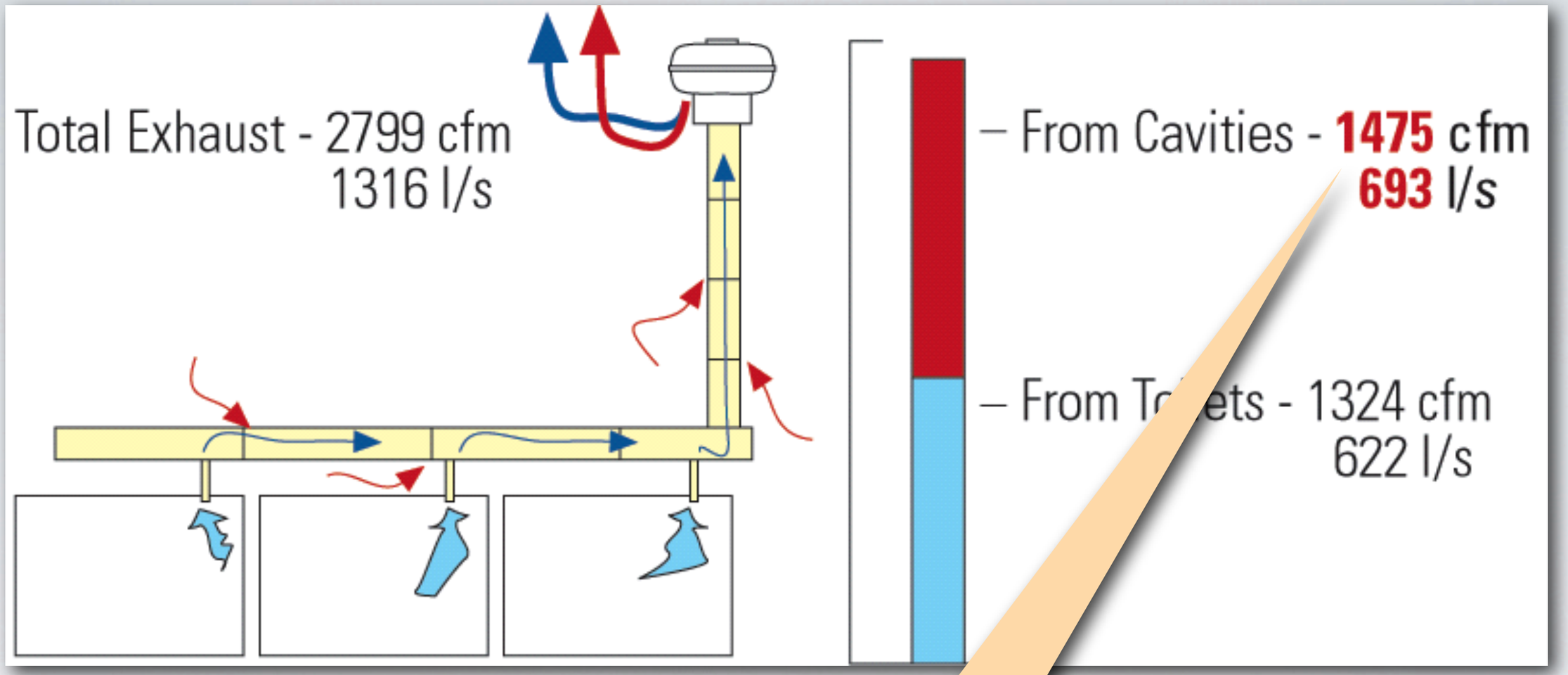


**More than 50% of exhaust is pulled from wall cavities—not the bathrooms**

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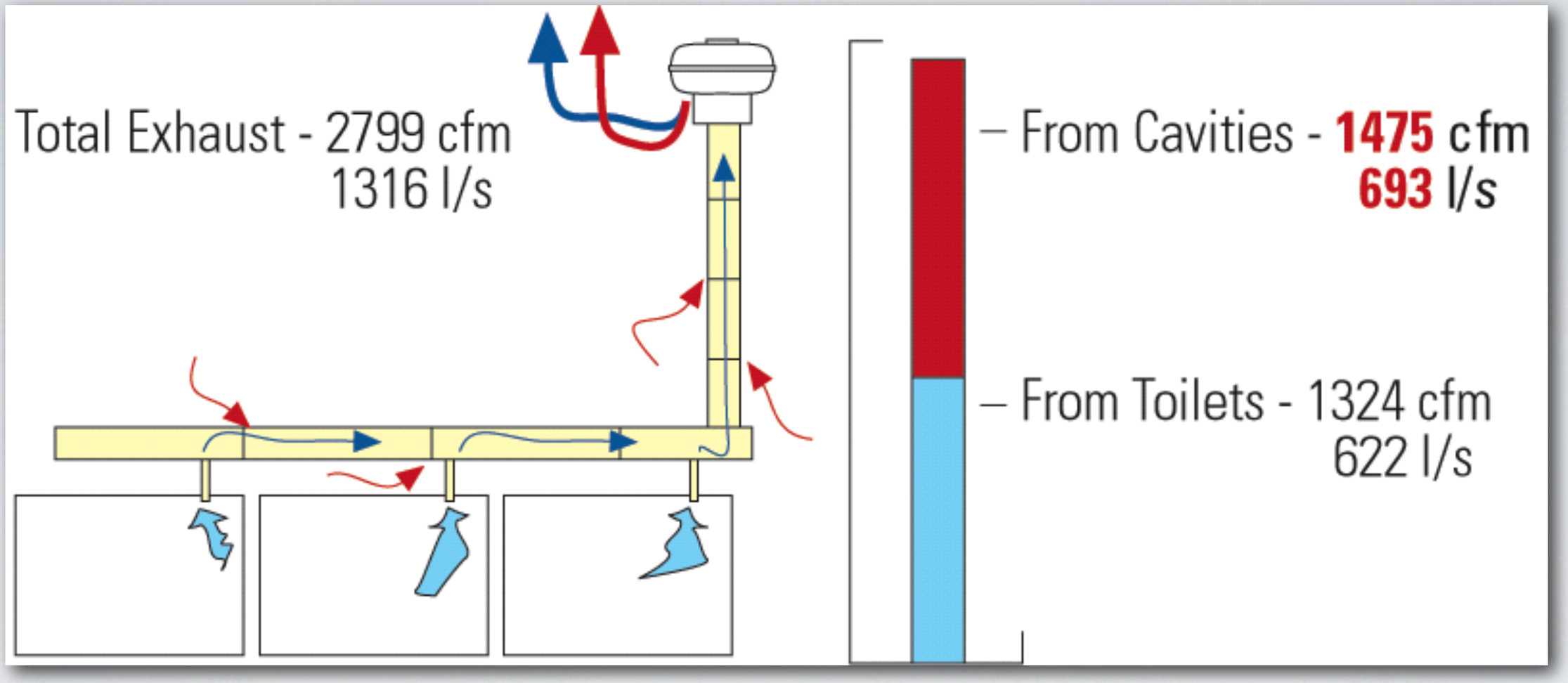

# Unoccupied hours - Problems and solutions



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Photograph 1: Mold growth on classroom wall aft



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Email Share Print A A A Text Size

**Clark County elementary school buildings closed indefinitely due to mold issues**

Recommend 2 recommendations. Sign Up to see what your friends recommend.

*Posted: Aug 15, 2011 4:00 PM EDT*

CLARK COUNTY, Mo. (WGEM) --A serious mold problem is delaying the first day of school for about 450 Clark County students. The school district has decided to start classes Monday for those students at the district's high school and middle



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- **Building is partly occupied - A few rooms are cooled, most are not. Mold grows on cold surfaces**

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- **Building is partly occupied - A few rooms are cooled, most are not. Mold grows on cold surfaces**
  - Short term - Operate cooling systems based on maximum dew point in unoccupied rooms, not on room temperature.

# Problems during unoccupied hours (2 of 2)

- **Ventilation air continues when indoor temperature set point is raised, flooding building with humid air**
  - Short term - Install motorized dampers to close off ventilation air when building is unoccupied.
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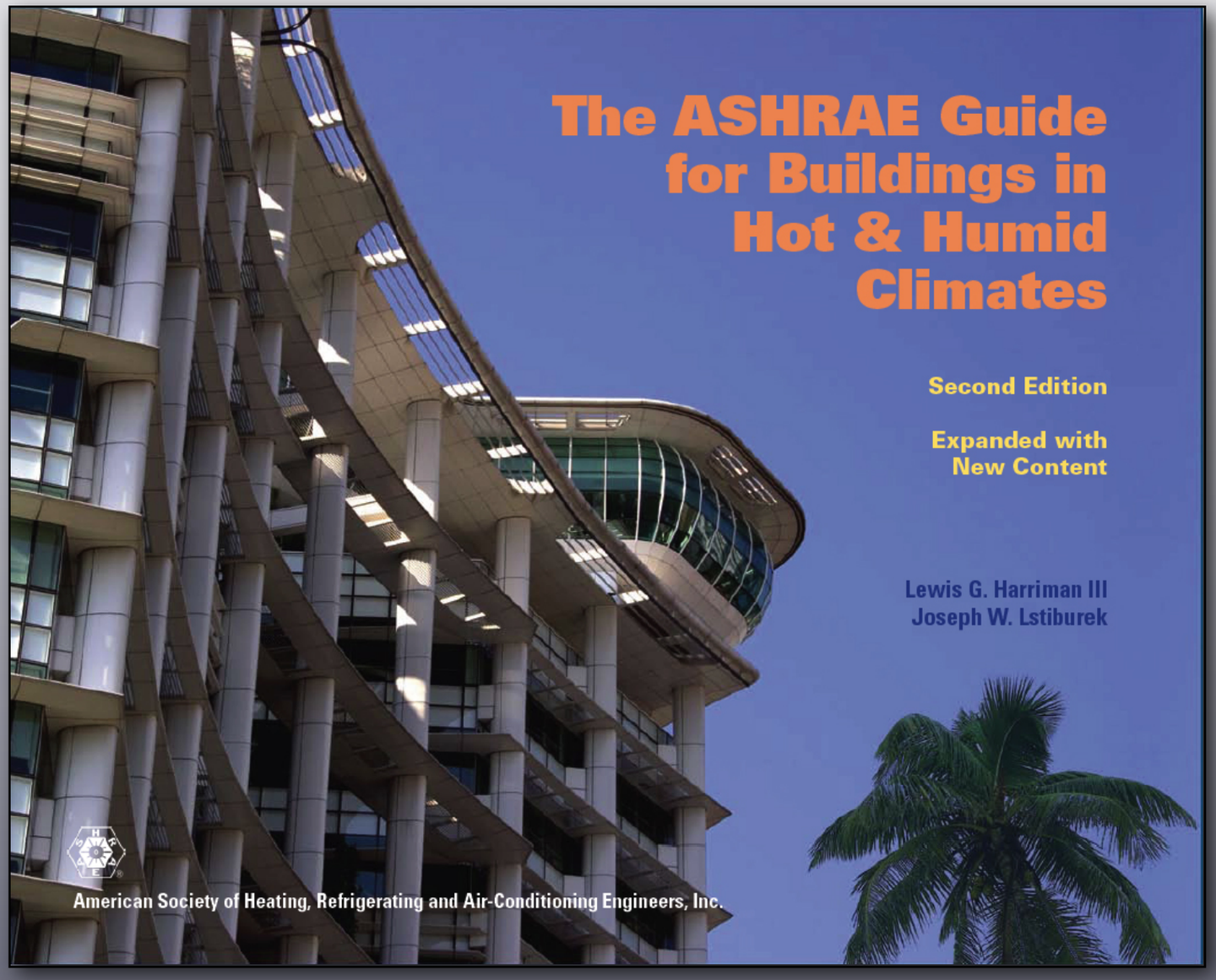
- Biggest humidity load?... Ventilation and makeup air, BY FAR the largest loads
- For easy humidity control - Dry the incoming air in a dedicated outdoor air system (DOAS)

## Section 3 of 3

# Suggestions for Buildings



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**Joseph W. Lstiburek, Ph.D, P.Eng.**

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## Common Issues

1. Introduction
2. Improving Thermal Comfort
3. Managing Ventilation Air
4. Reducing Energy Consumption
5. Avoiding Bugs, Mold & Rot
6. Improving Sustainability

## Enclosure Design

7. The Components of a Perfect Wall
8. Keeping Water Out of the Building
9. Keeping Heat Out of the Building
10. Architectural Lessons From Tropical Storms

## HVAC Design

11. Estimating Dehumidification Loads
12. Estimating Cooling Loads
13. Designing Dehumidification Systems
14. Designing Cooling Systems
15. Designing Ventilation Systems
16. Air-Tight HVAC Systems

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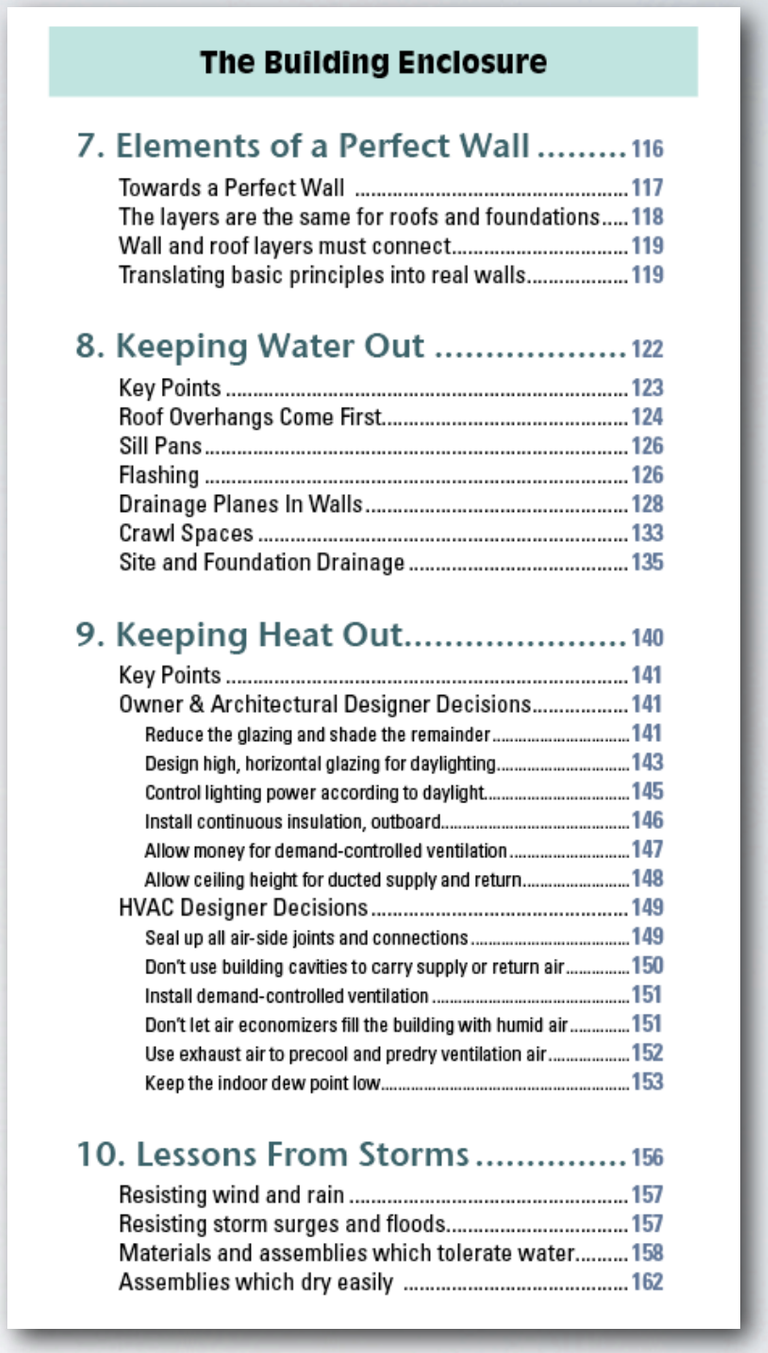

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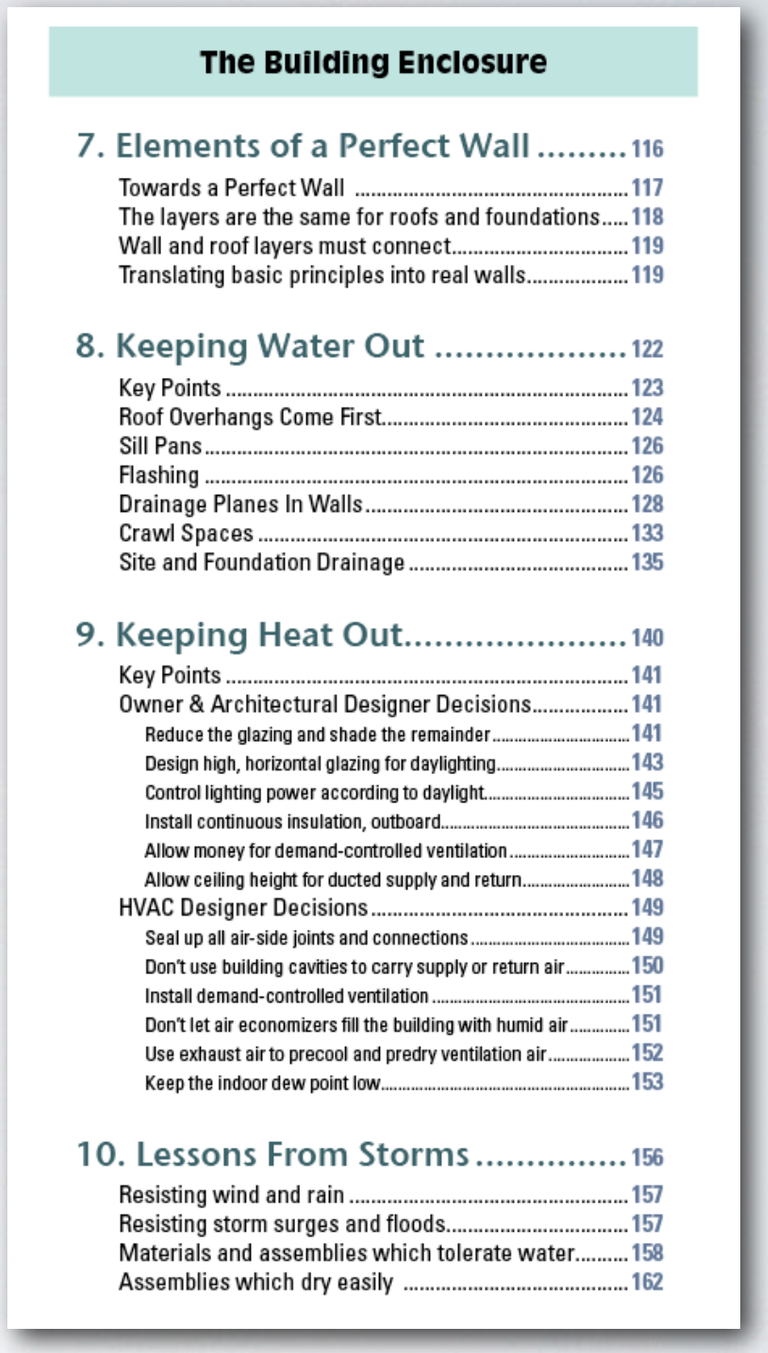
## 3 of My Favorite Suggestions:



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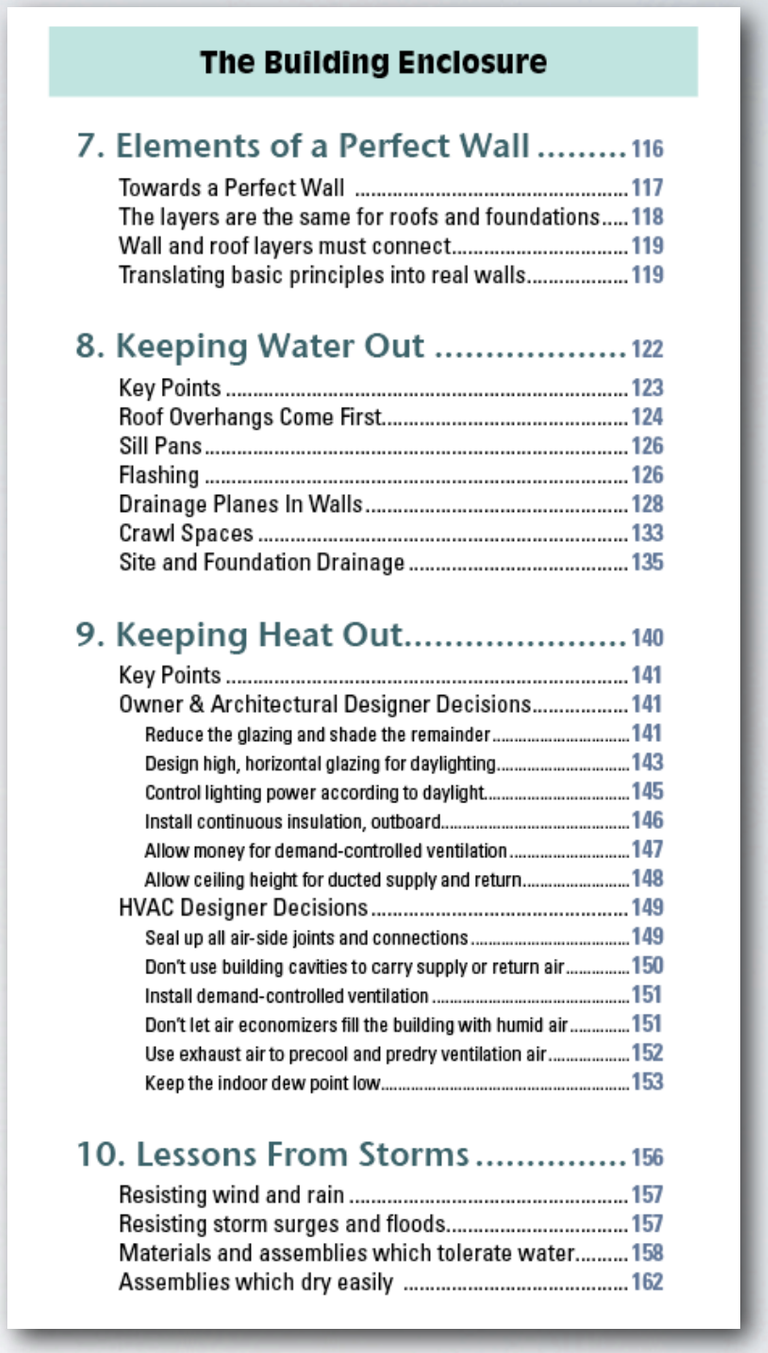
- **Focus on glazing**... Daylighting and low solar heat gain.



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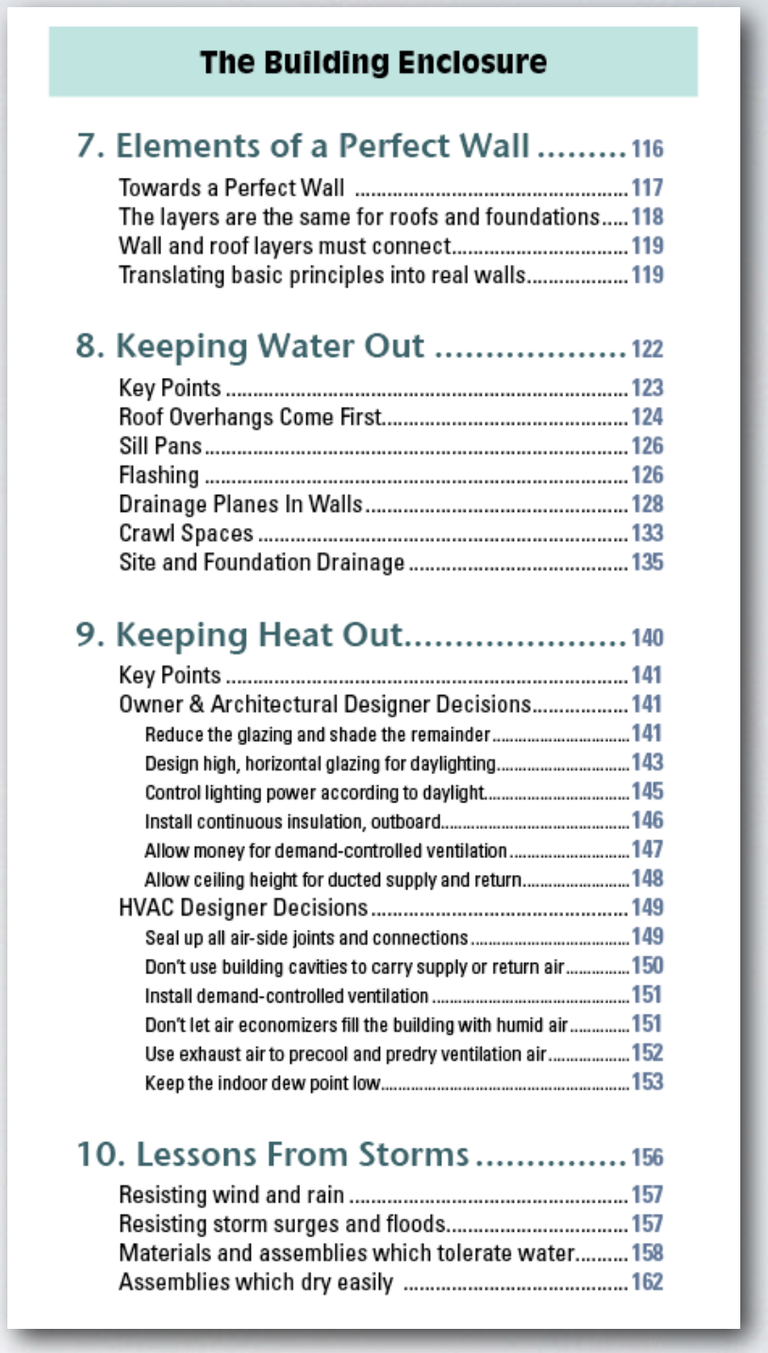
# Suggestions for architectural design

## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.



**The Building Enclosure**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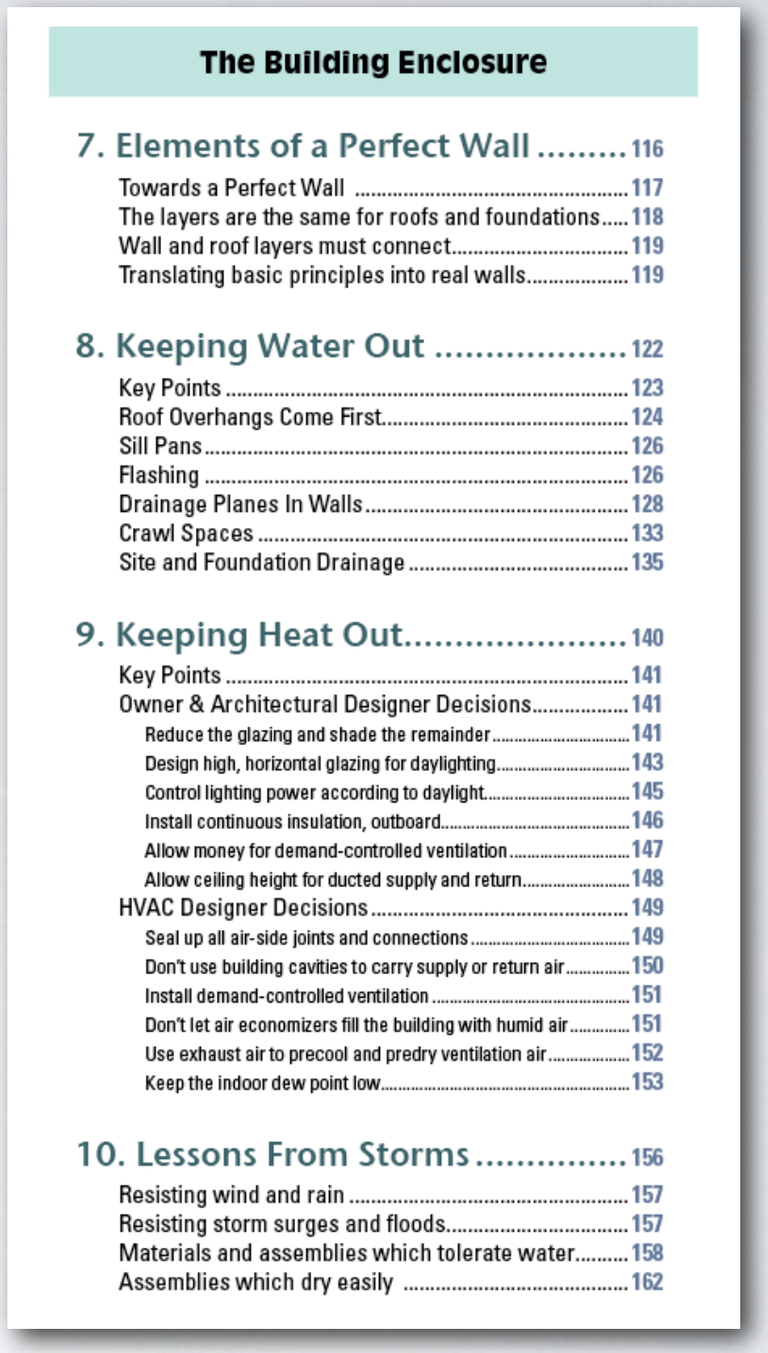
# Suggestions for architectural design

## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.
- **Indoor insulation and air tightness**... For partly-cooled buildings.



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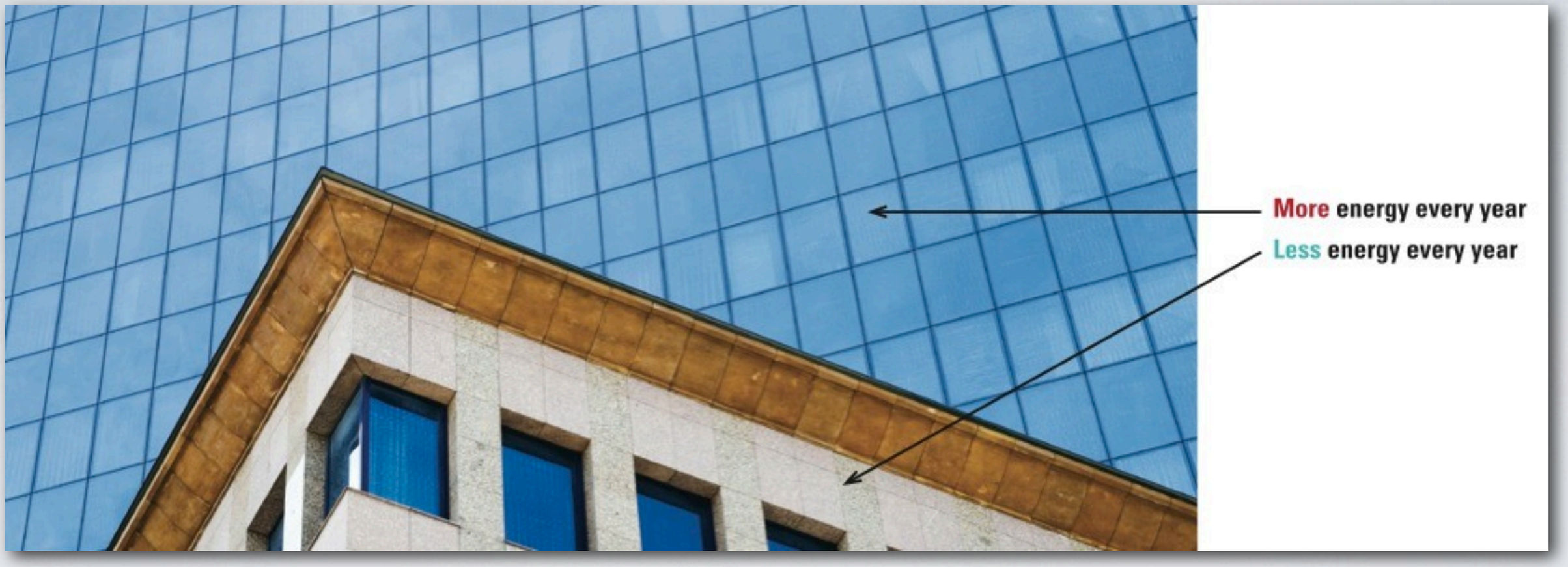
# Less glass = smaller cooling system = less energy!



# Time of day and air temperatures



# Time of day and air temperatures






# Time of day and air temperatures









# Manila - Shangri-La Hotel



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# Manila - Shangri-La Hotel - Surface temperatures



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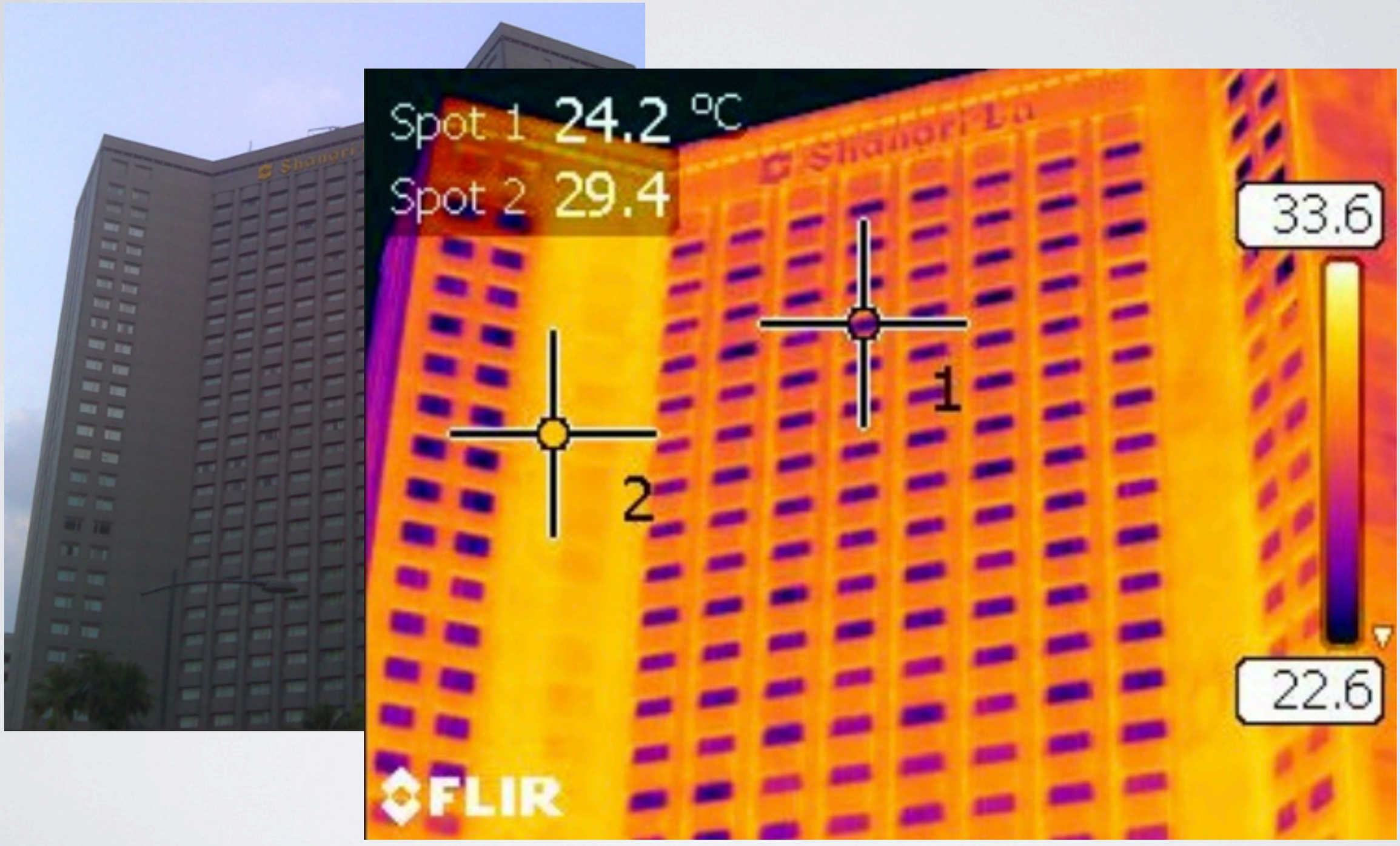
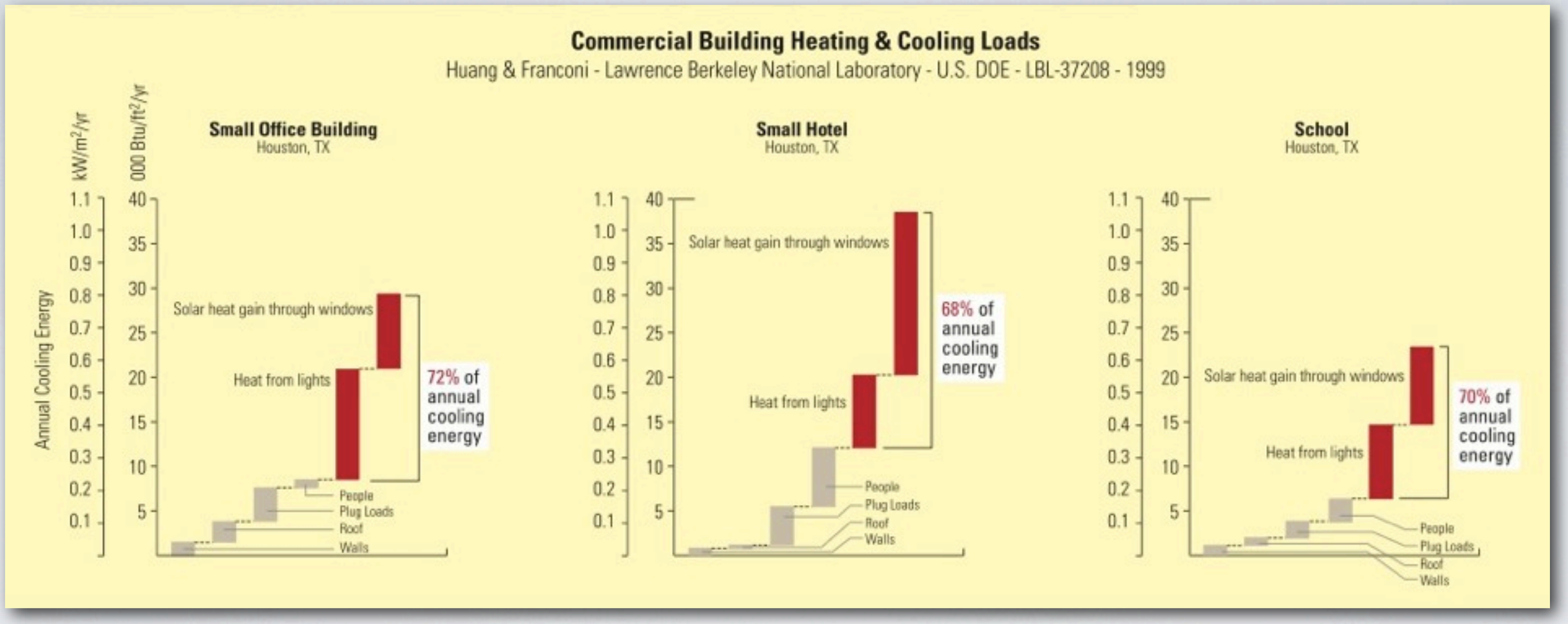
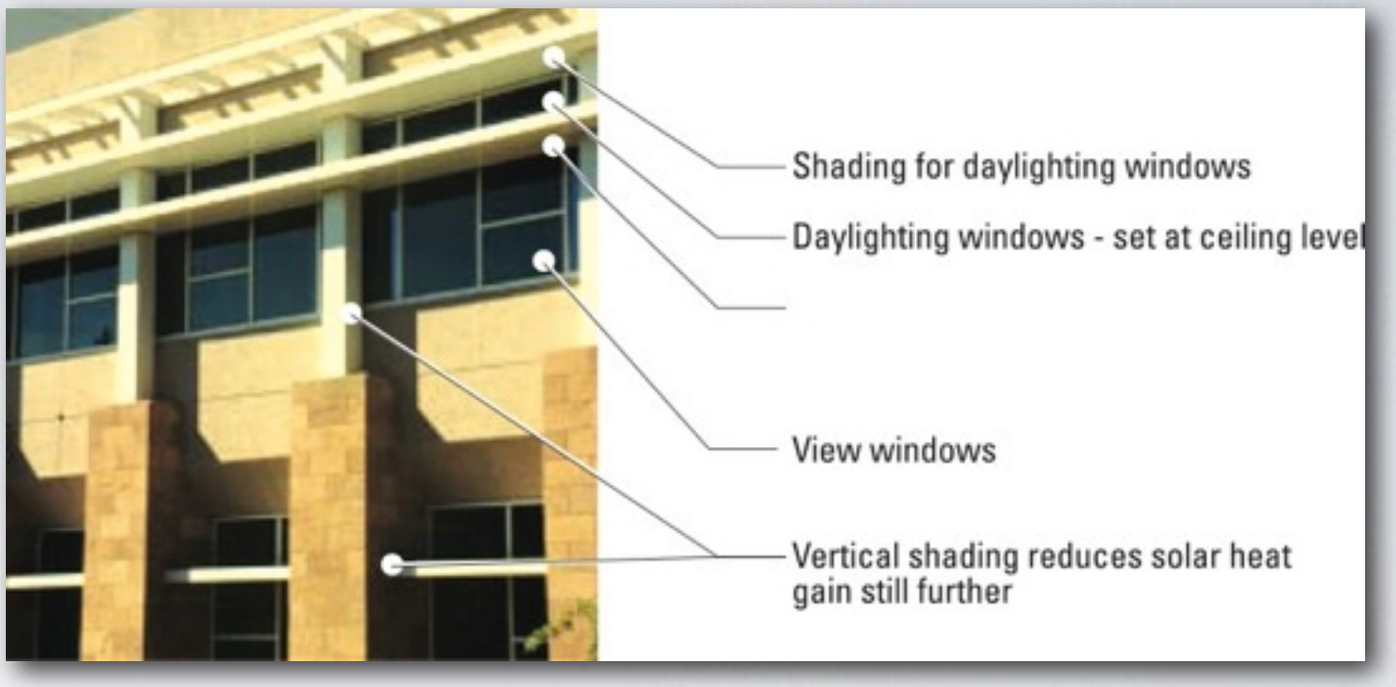


# HVAC cooling loads in commercial buildings depend on the architect's glazing decisions

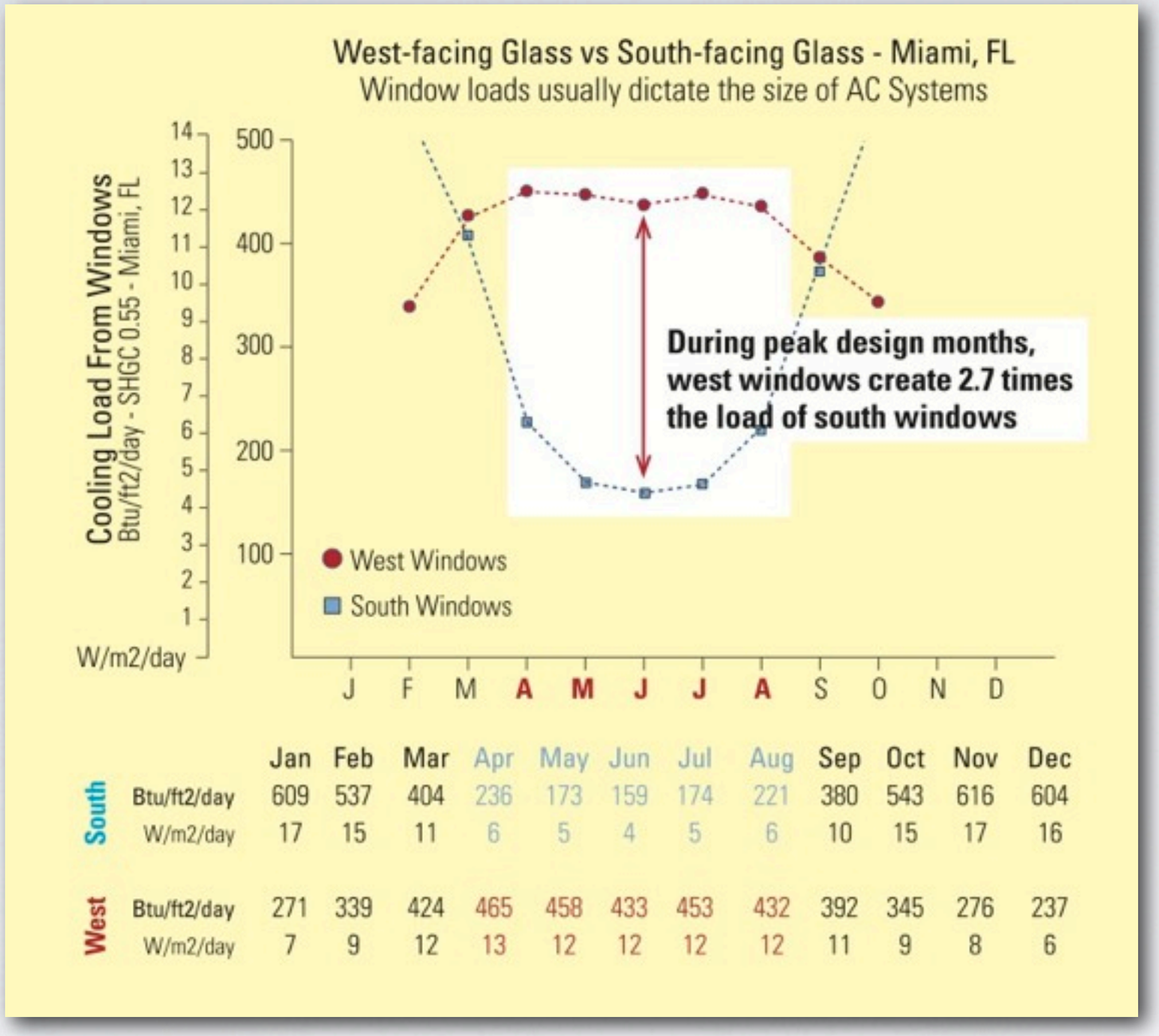


# Even better than shading... Design for daylighting





# West-facing glass dictates the size of the cooling equipment (It governs the PEAK cooling load)




| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South | Btu/ft2/day | 609 | 537 | 404 | 236 | 173 | 159 | 174 | 221 | 380 | 543 | 616 | 604 |
| | W/m2/day | 17 | 15 | 11 | 6 | 5 | 4 | 5 | 6 | 10 | 15 | 17 | 16 |
| West | Btu/ft2/day | 271 | 339 | 424 | 465 | 458 | 433 | 453 | 432 | 392 | 345 | 276 | 237 |
| | W/m2/day | 7 | 9 | 12 | 13 | 12 | 12 | 12 | 12 | 11 | 9 | 8 | 6 |

# If glass cannot be avoided—shade it



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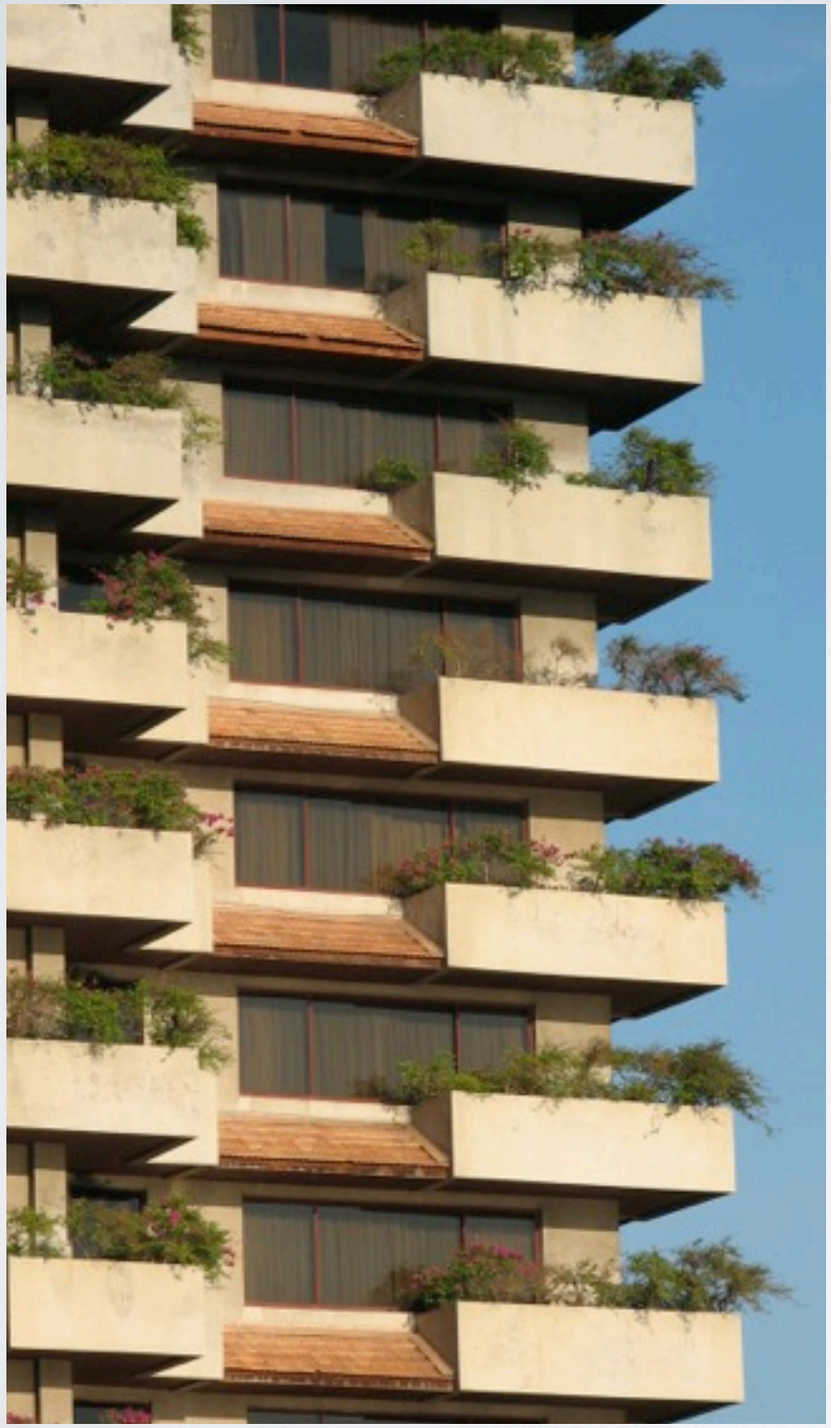



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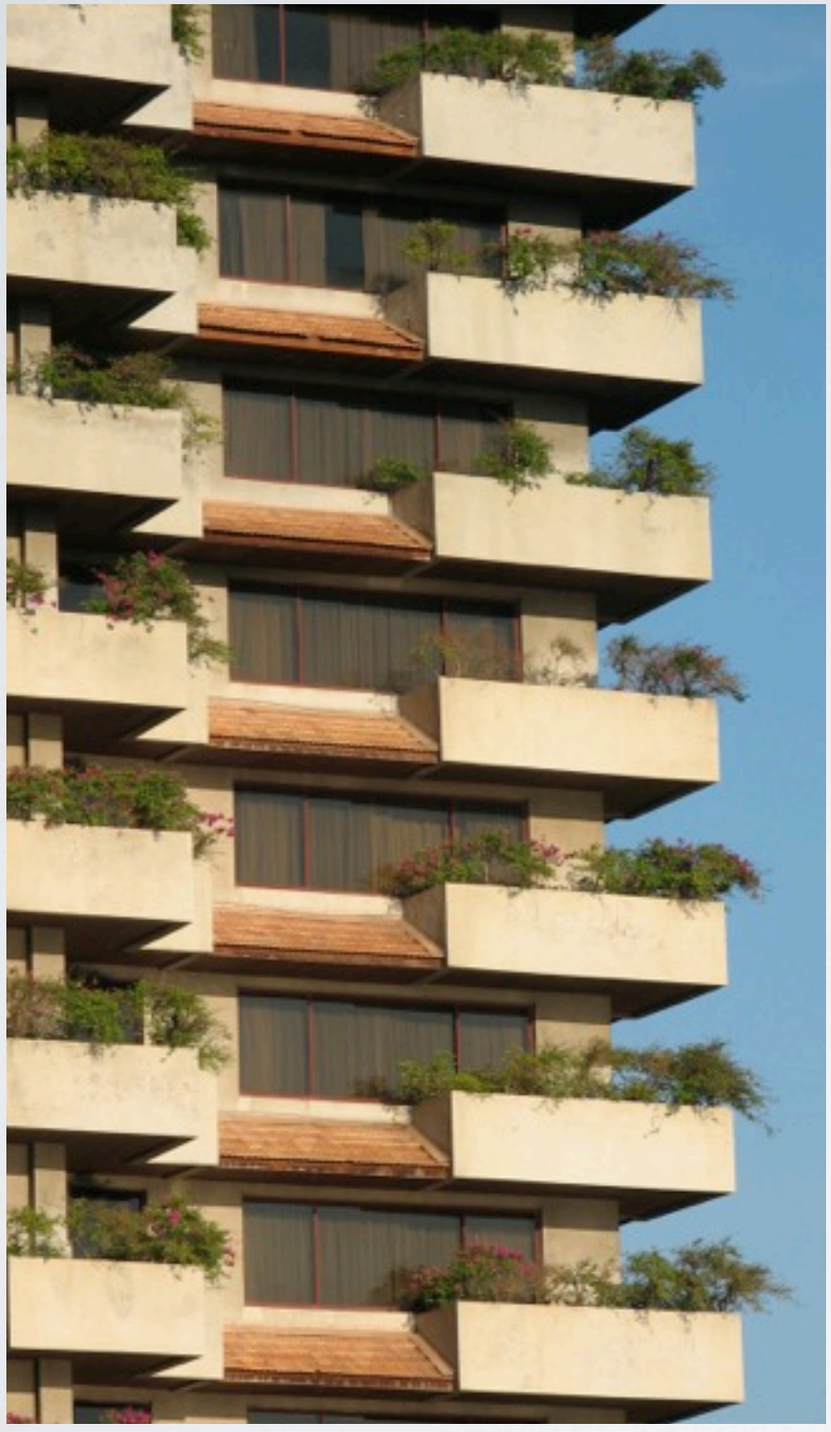



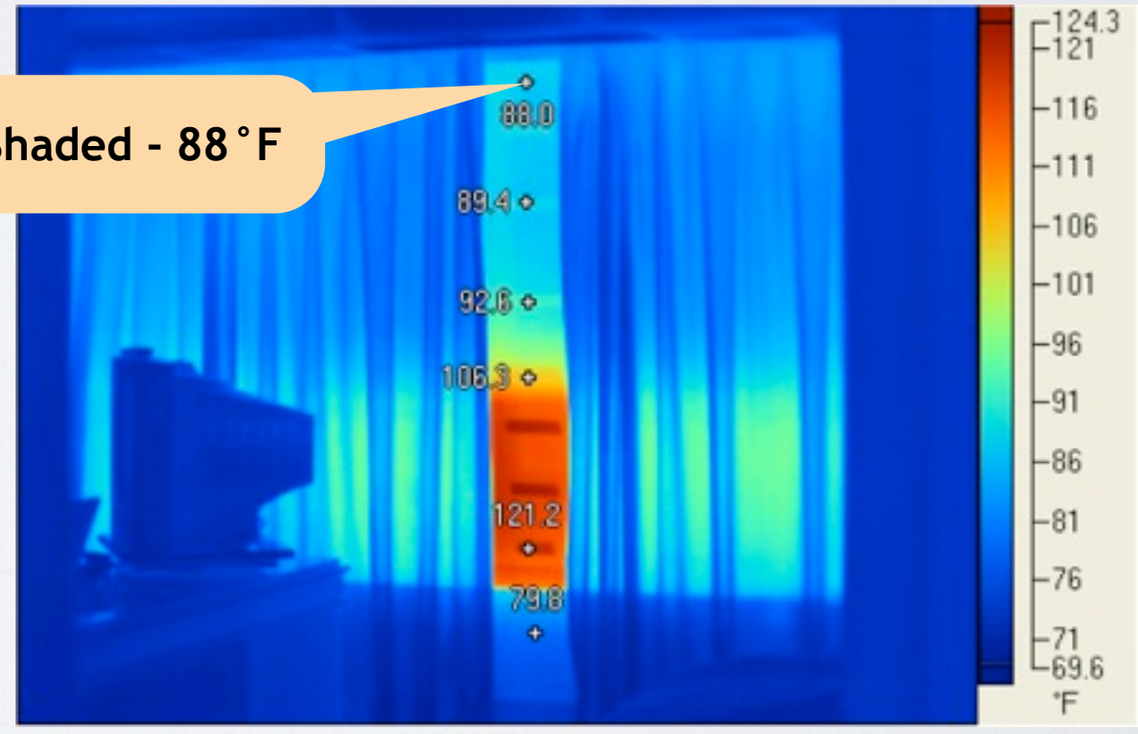

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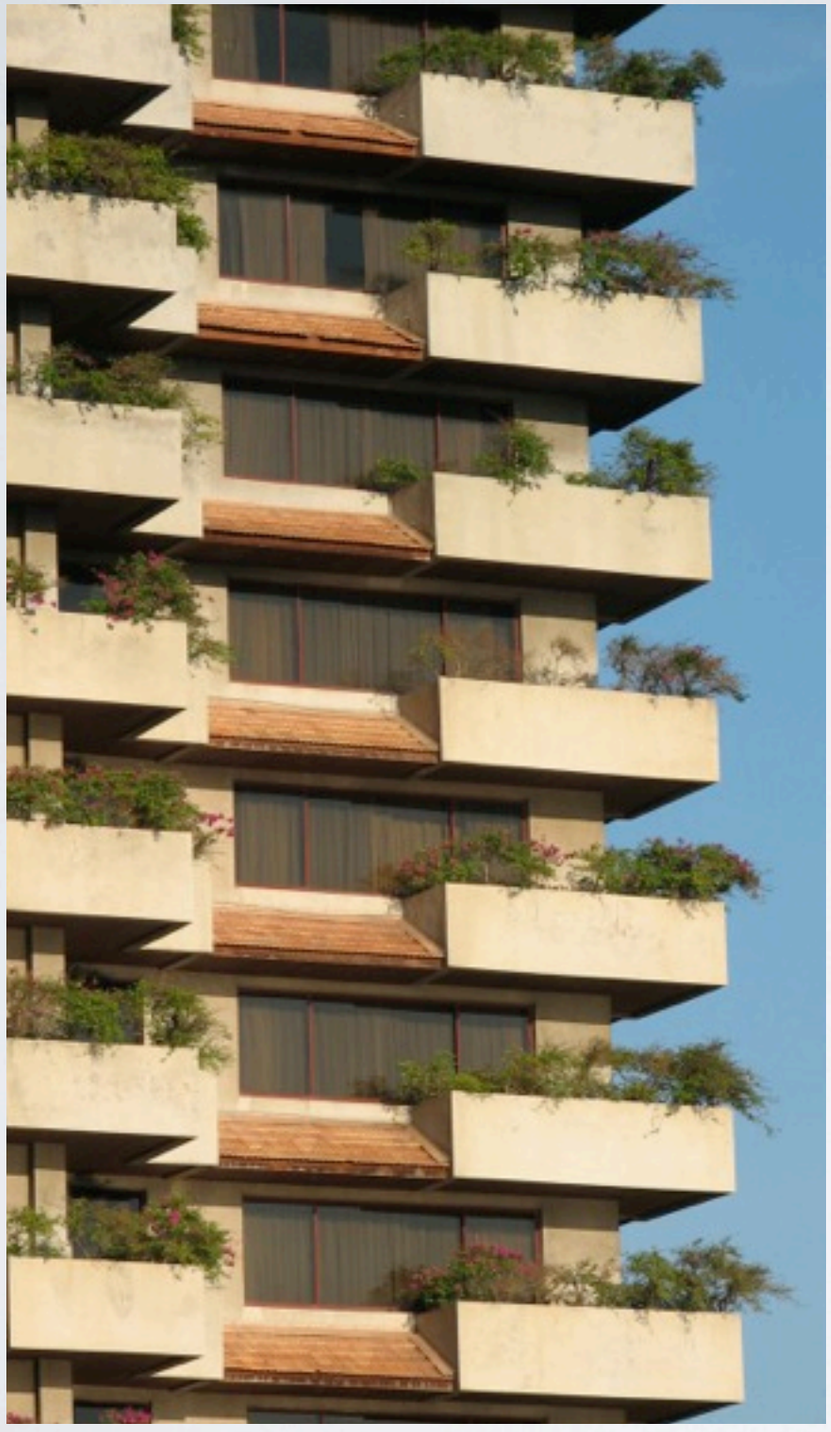
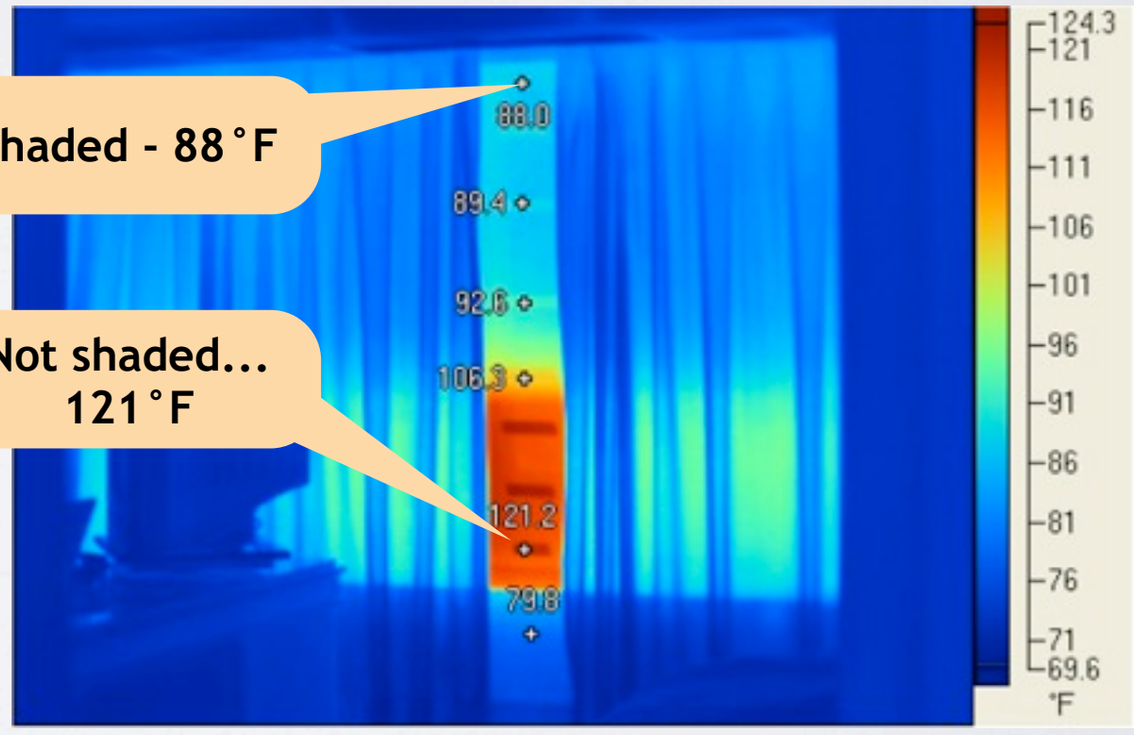
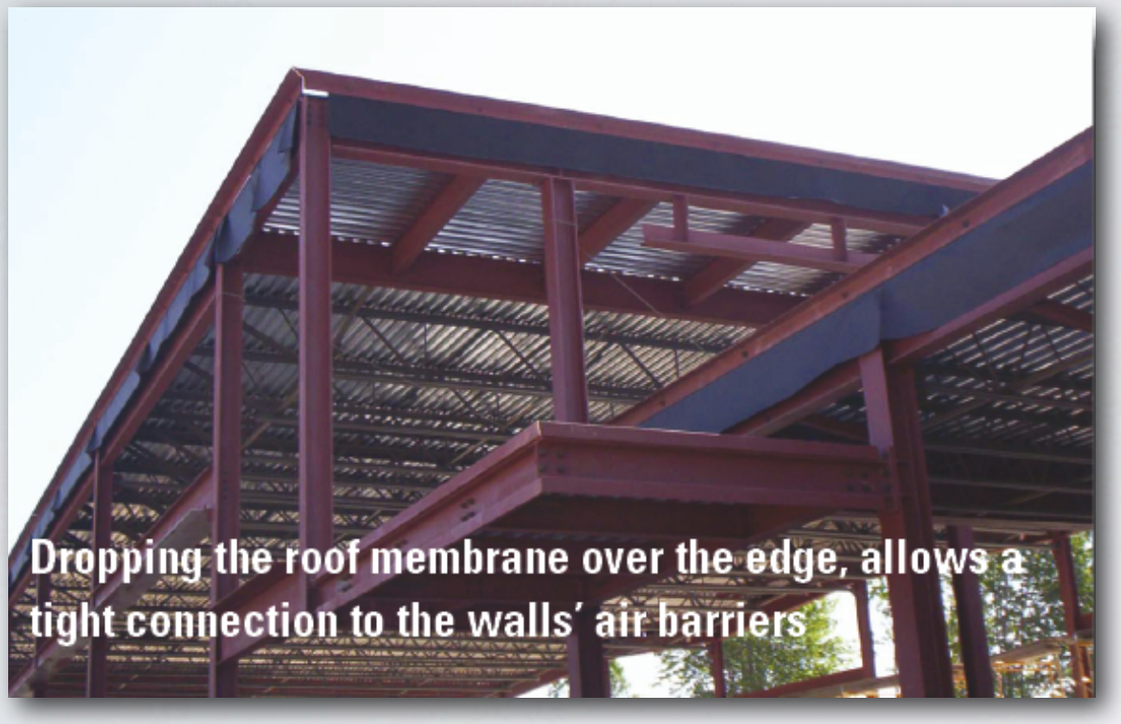


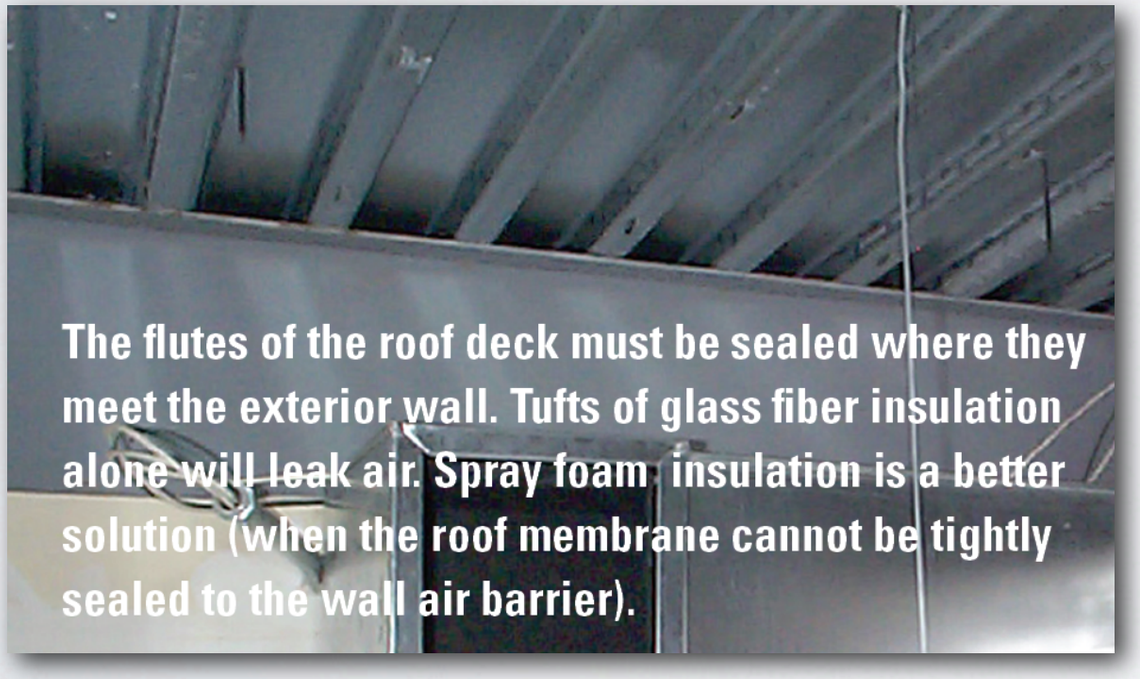




# Air-tight Buildings

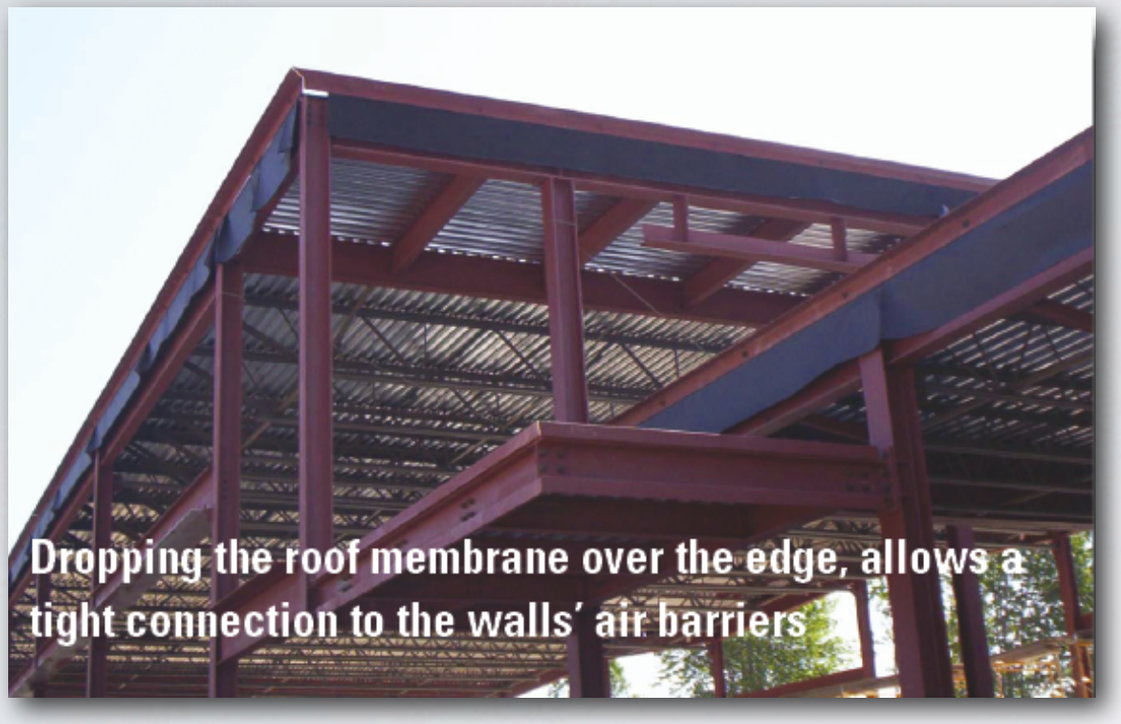


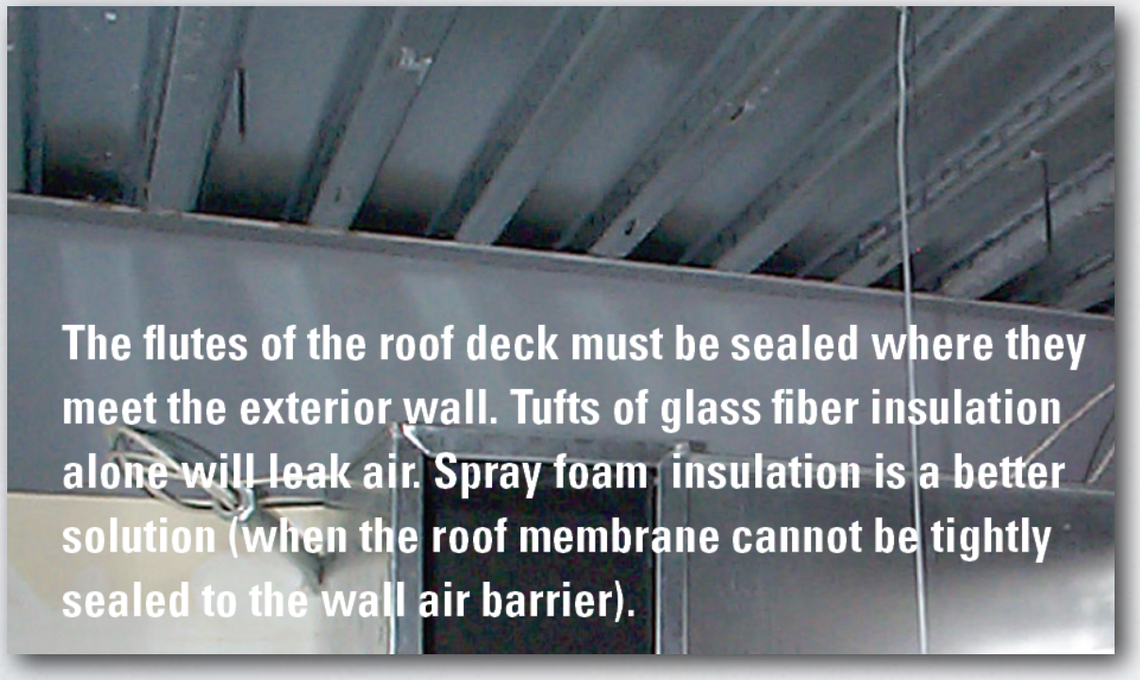
Dropping the roof membrane over the edge, allows a tight connection to the walls' air barriers

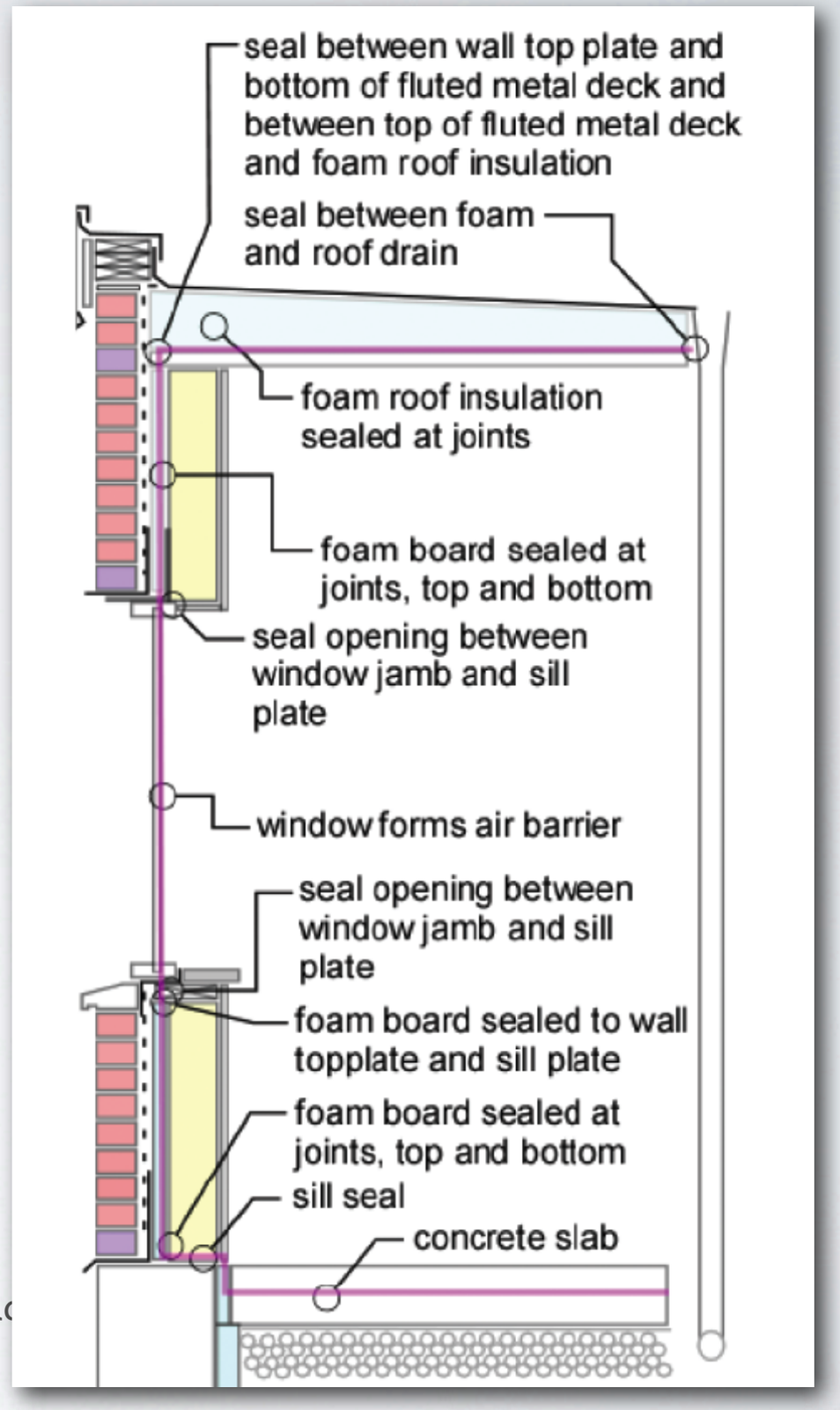


The flutes of the roof deck must be sealed where they meet the exterior wall. Tufts of glass fiber insulation alone will leak air. Spray foam insulation is a better solution (when the roof membrane cannot be tightly sealed to the wall air barrier).

# Air-tight Buildings



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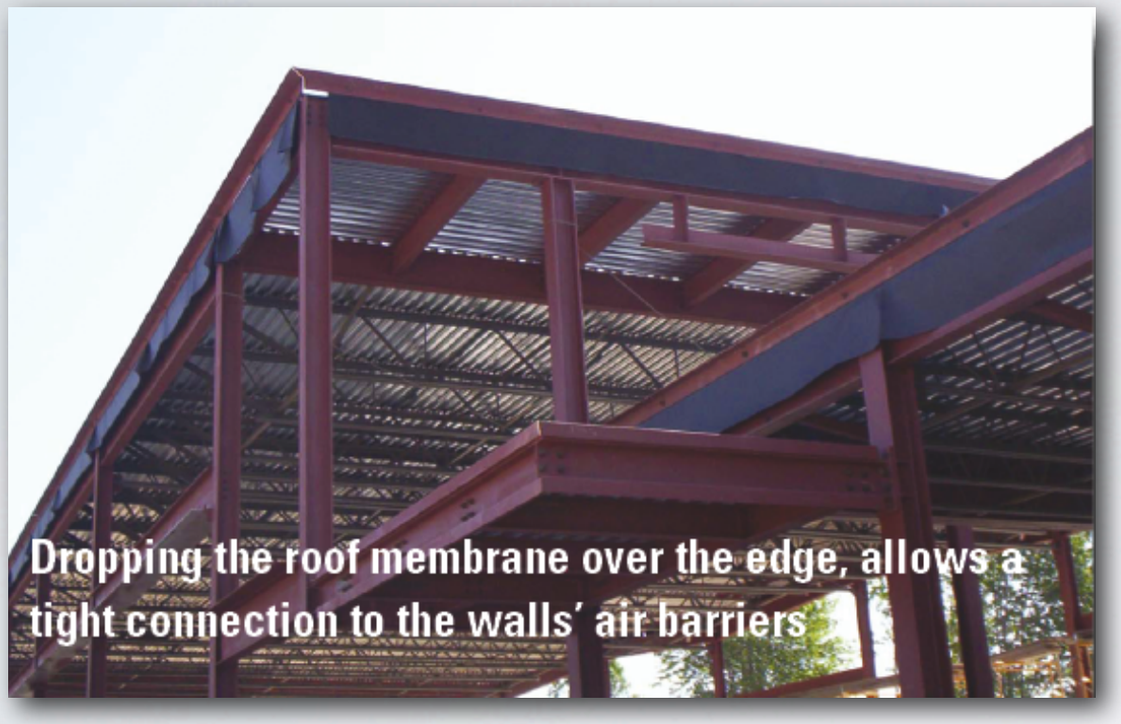
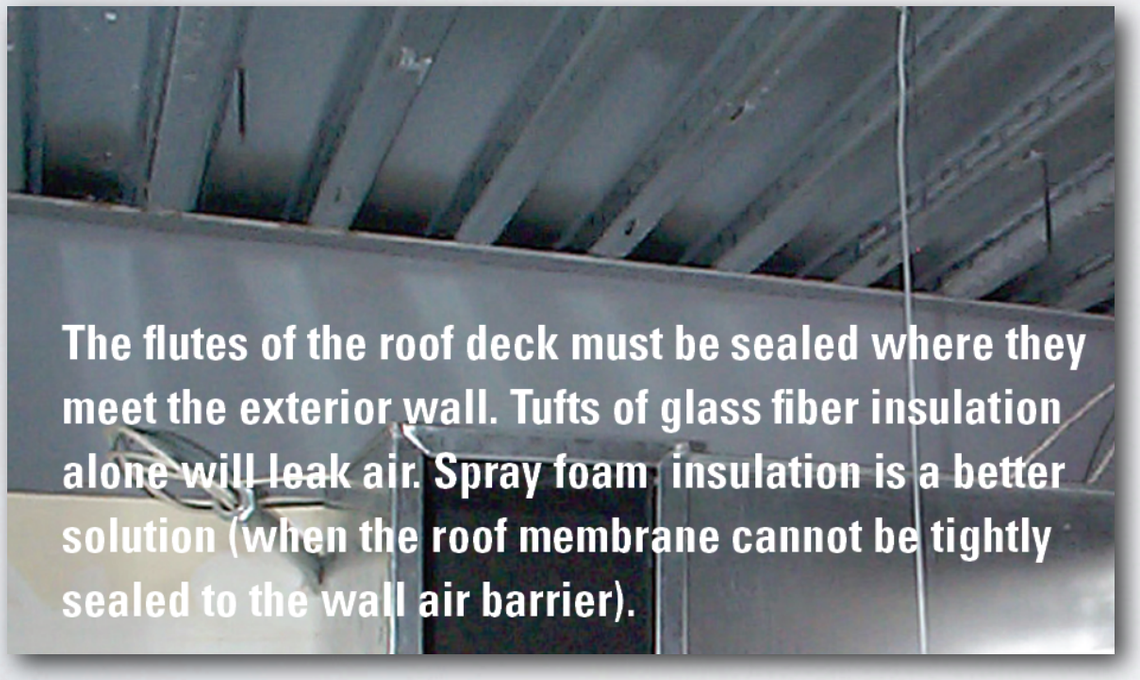
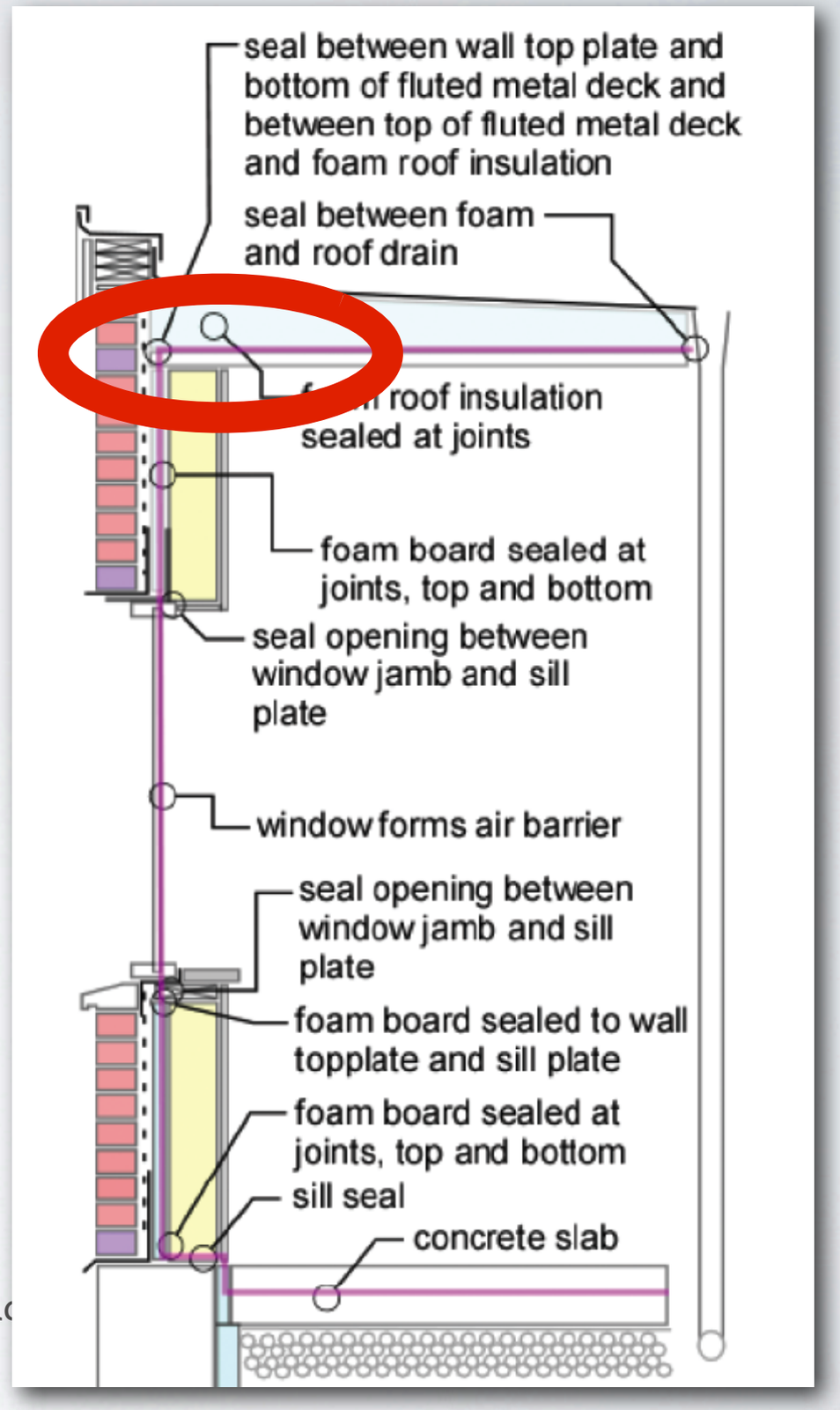


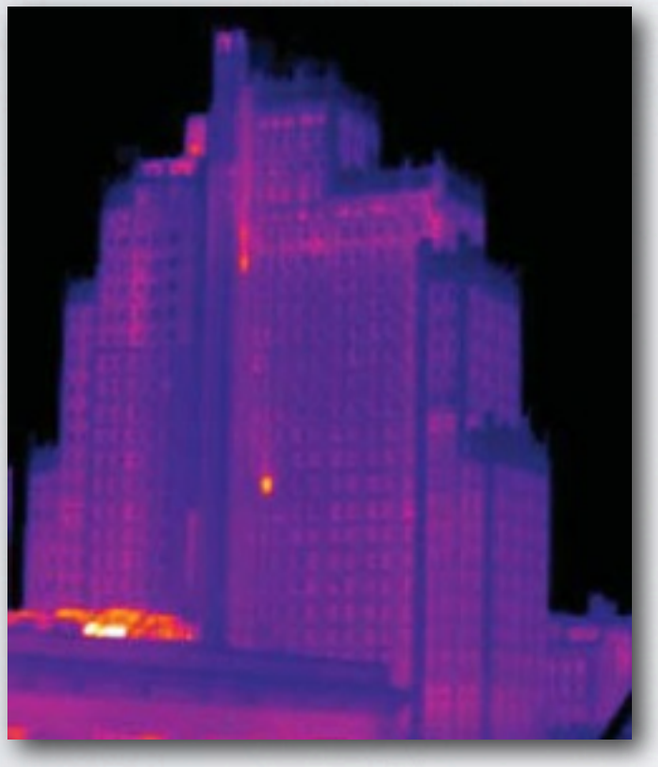



# Reason #1 - Mold prevention



# Reason #2 - Energy waste



# Reason #2 - Energy waste



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**80-year-old building**
**Some air leakage**



**30-year-old building**
**Less air leakage**



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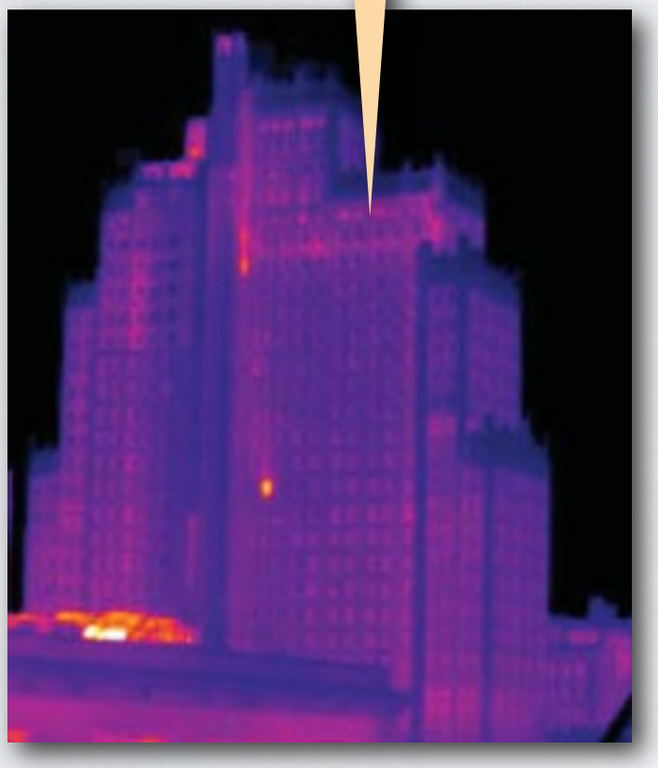
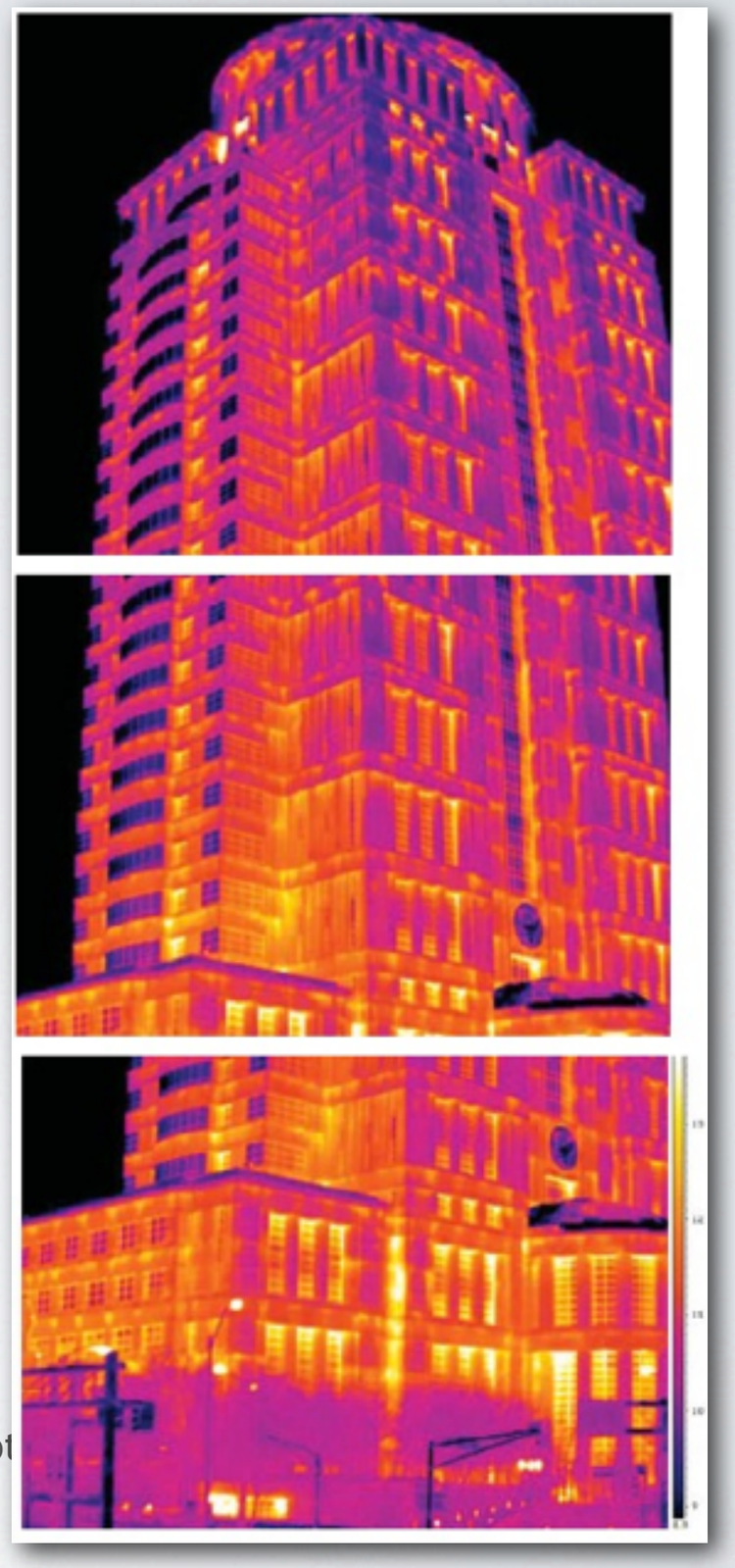


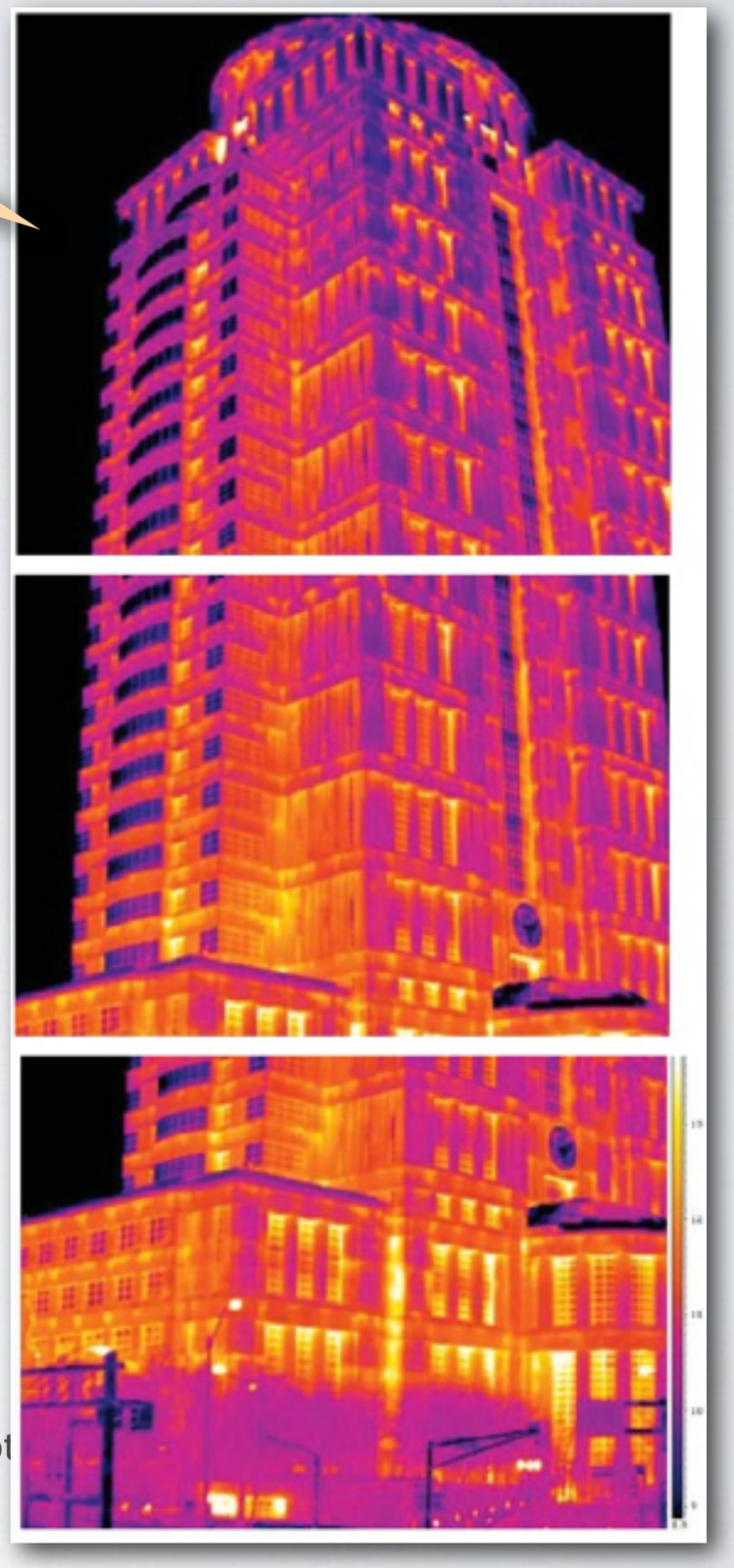
**30-year-old building**
**Less air leakage**



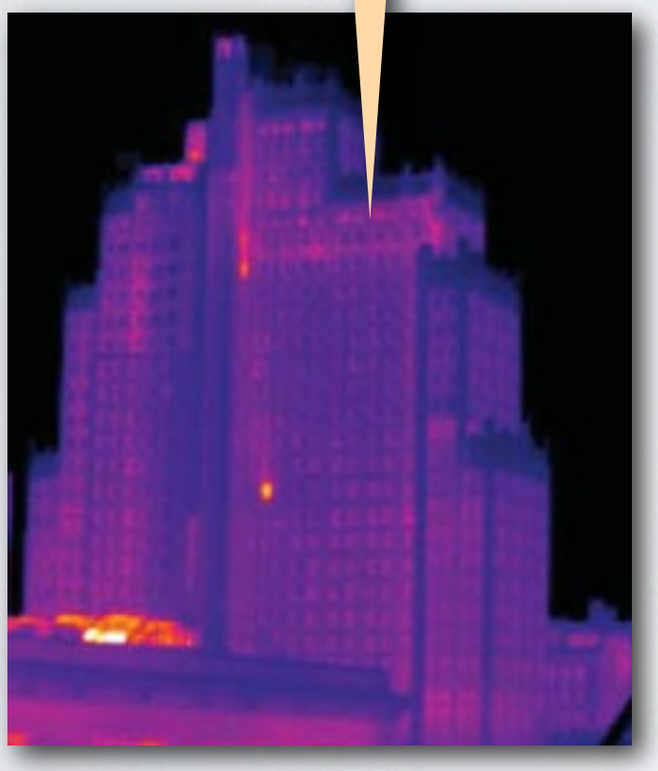


# Reason #2 - Energy waste

**2003 building...**
**HUGE air leakage**



**80-year-old building**
**Some air leakage**



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# “Stack effect” pressure differences drive air leakage

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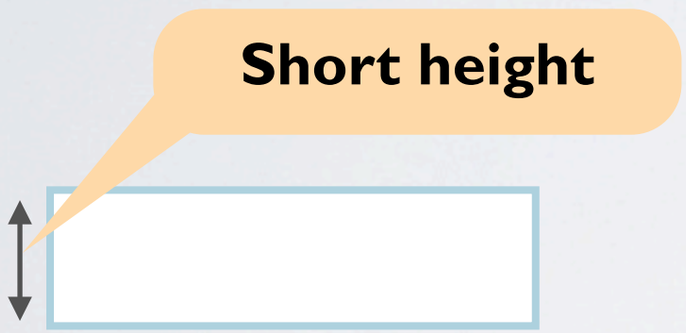

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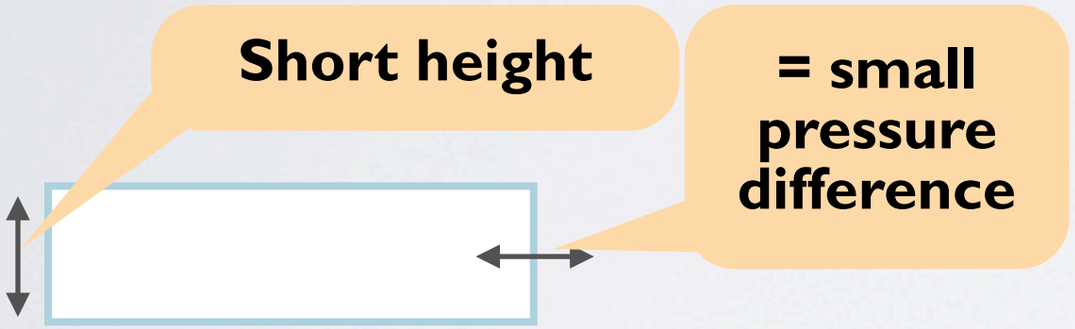

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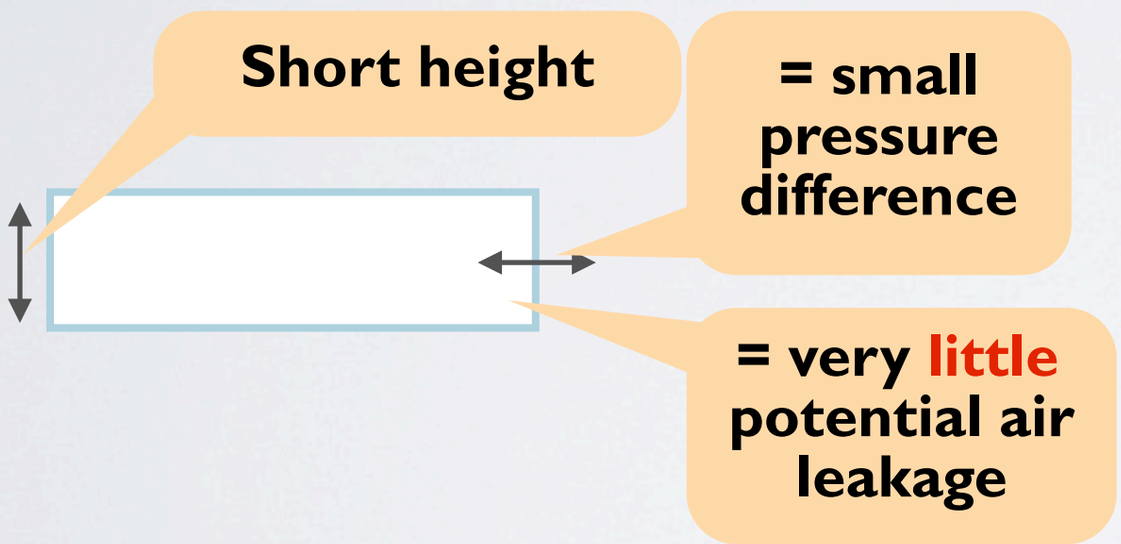

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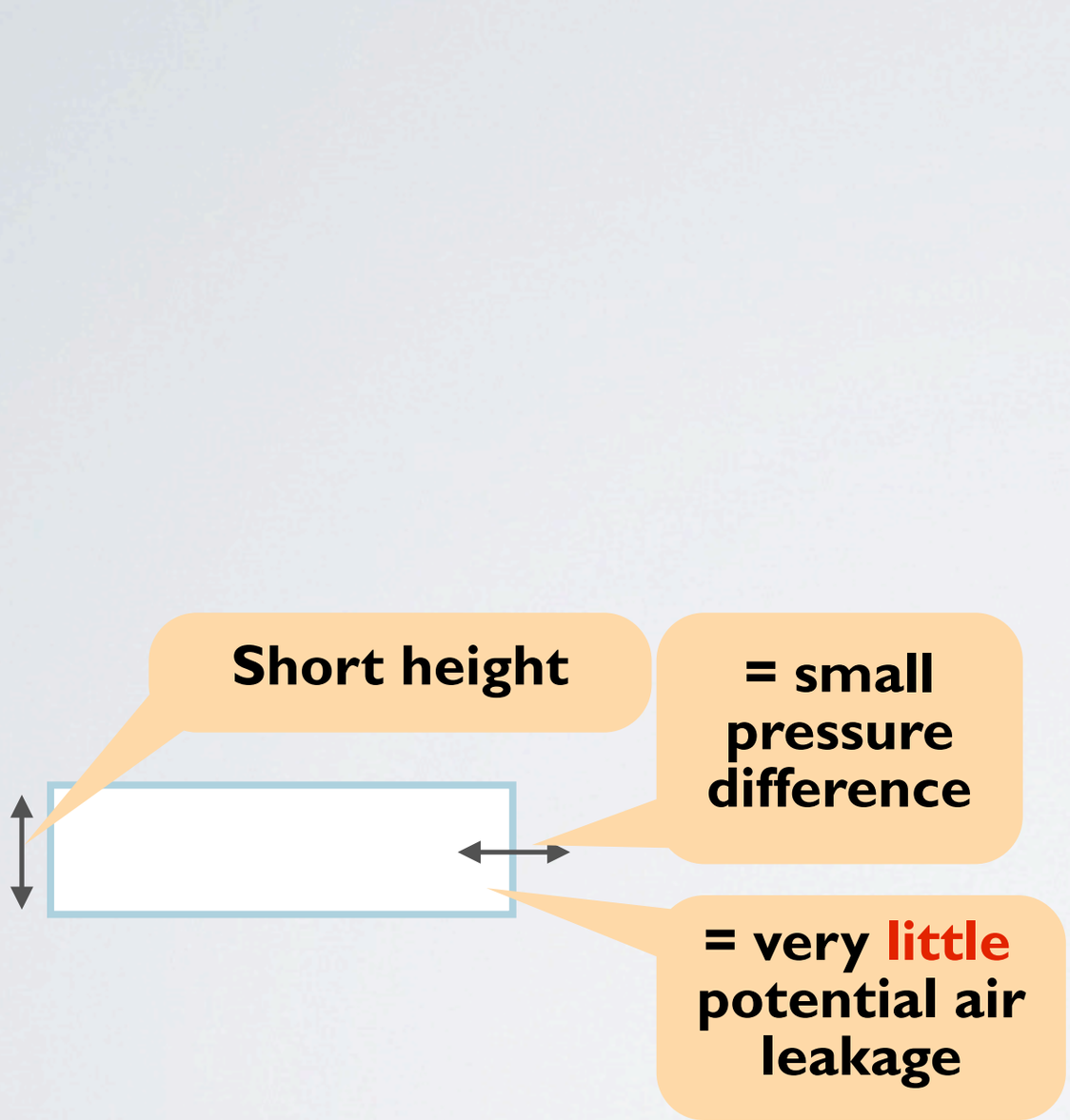

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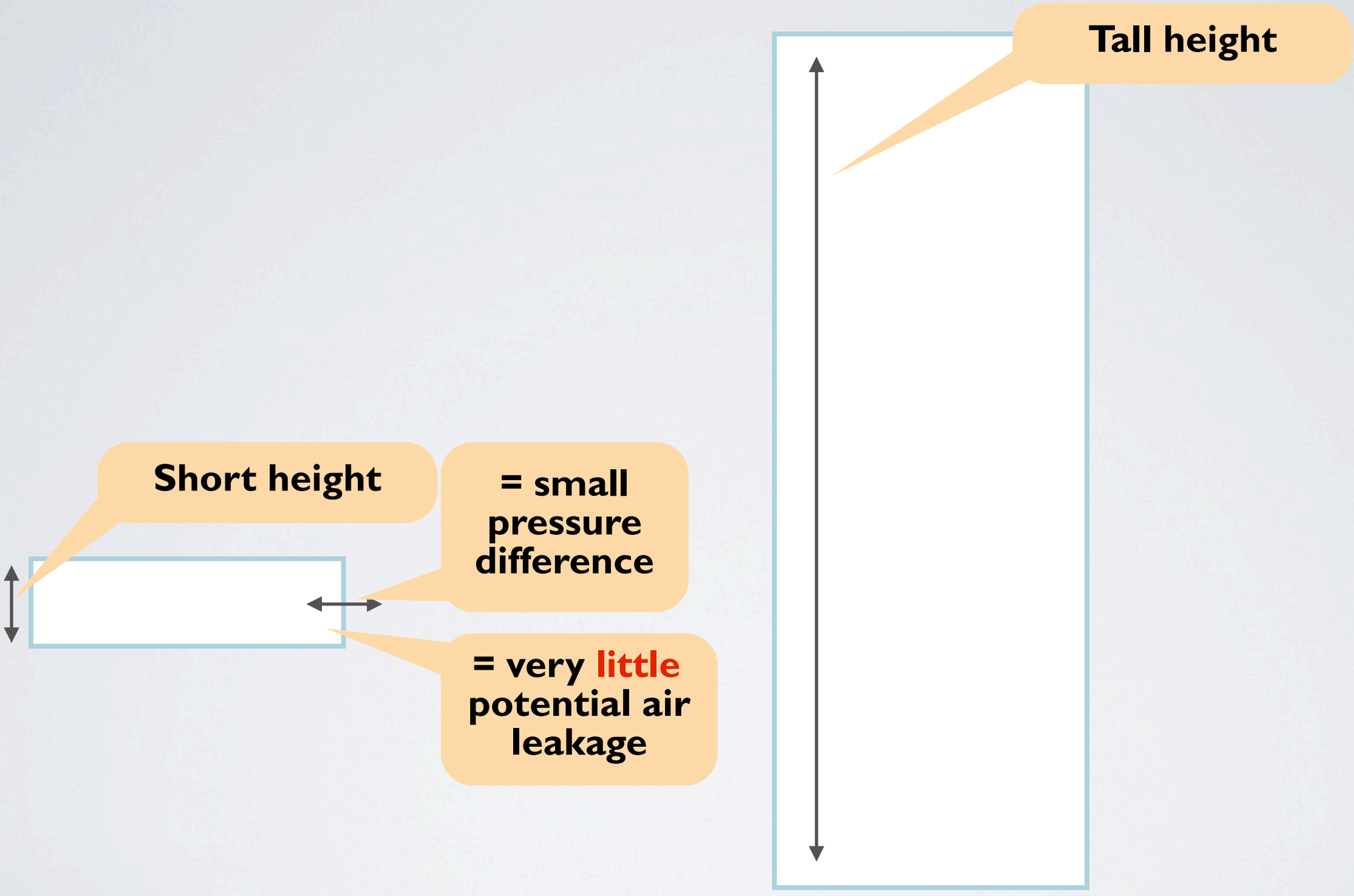

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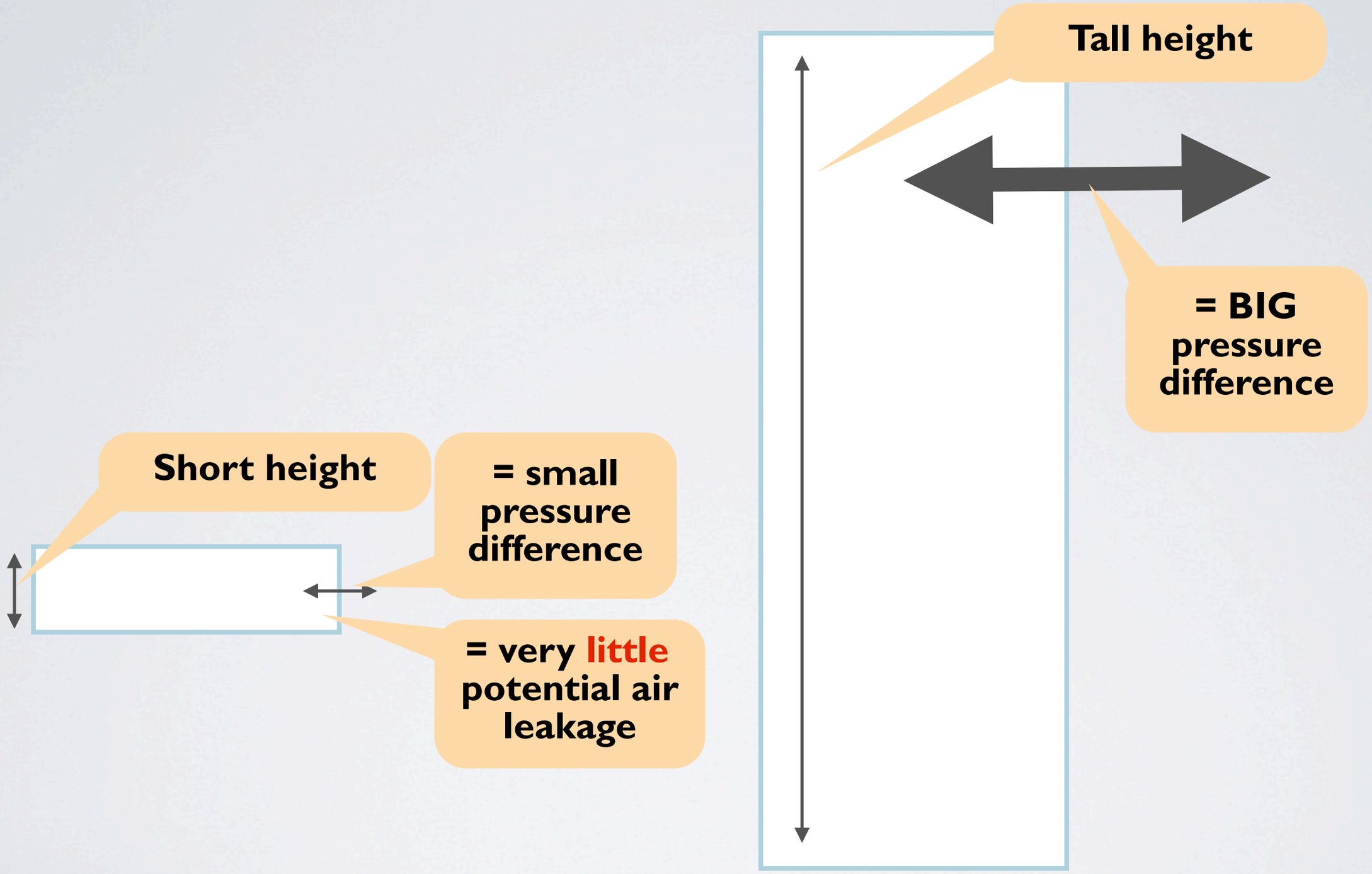

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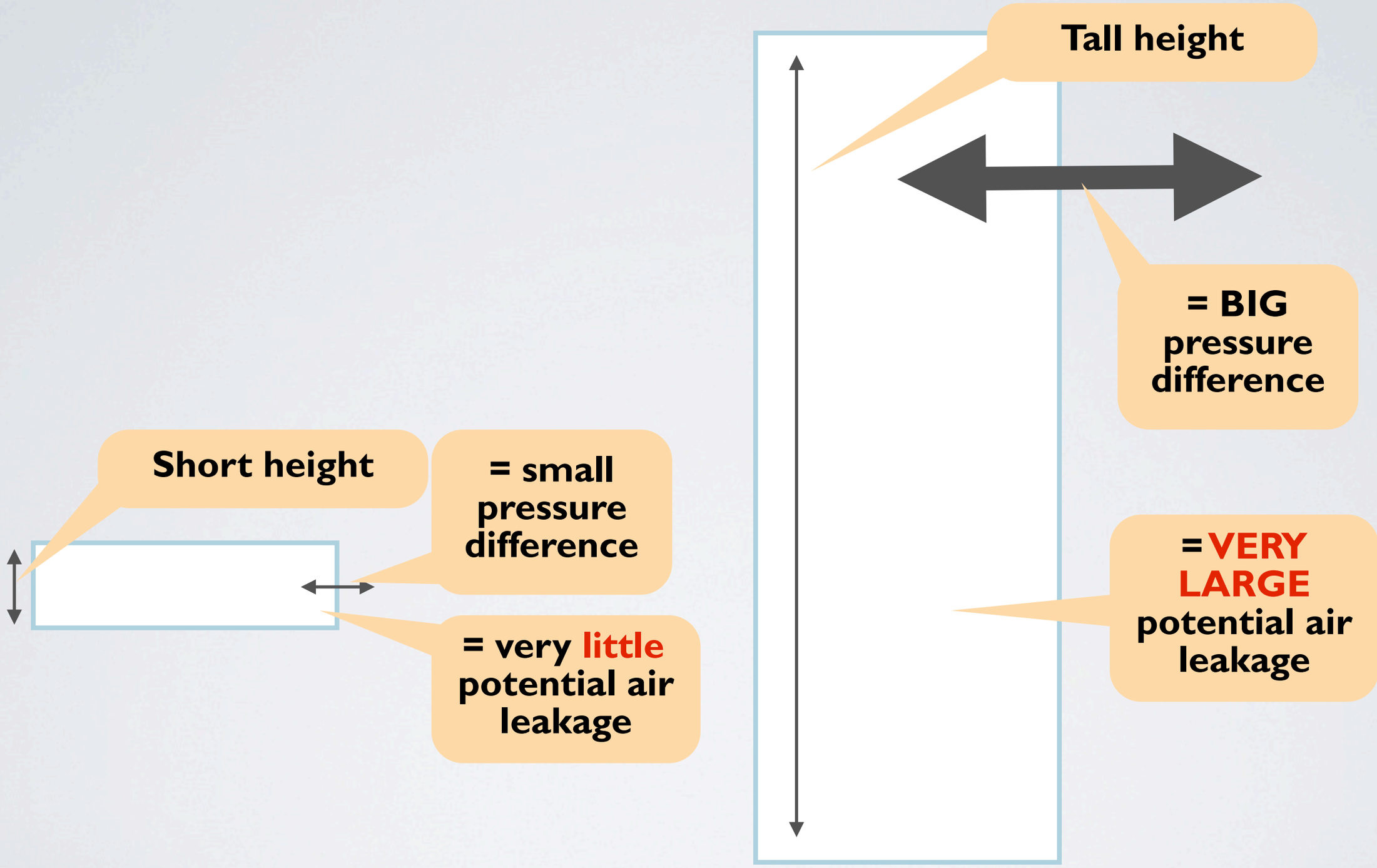
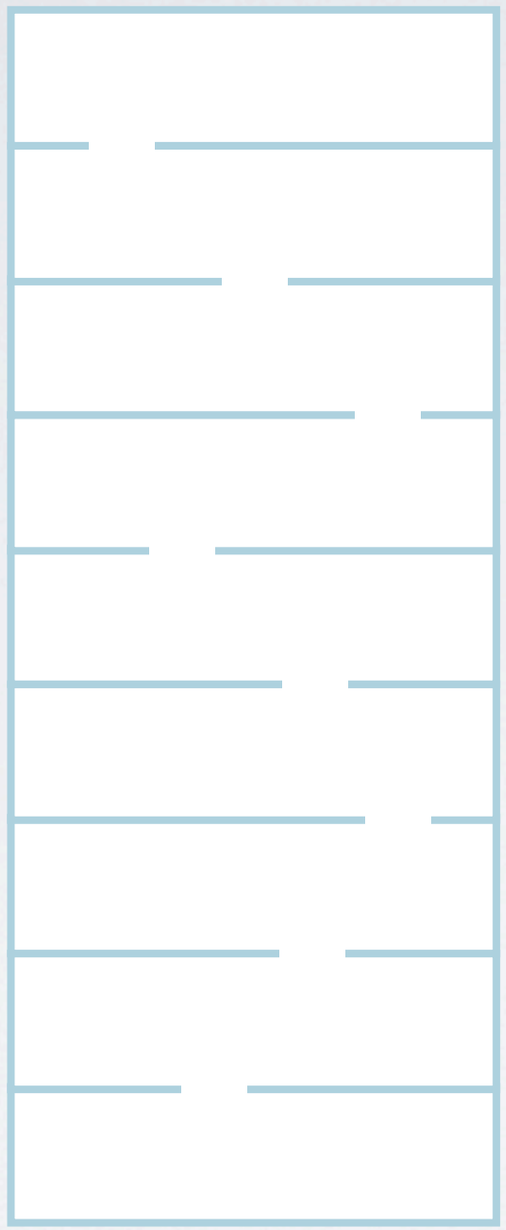


# Cold climate - Hot air rises, leakage enters at the bottom

Poor Building



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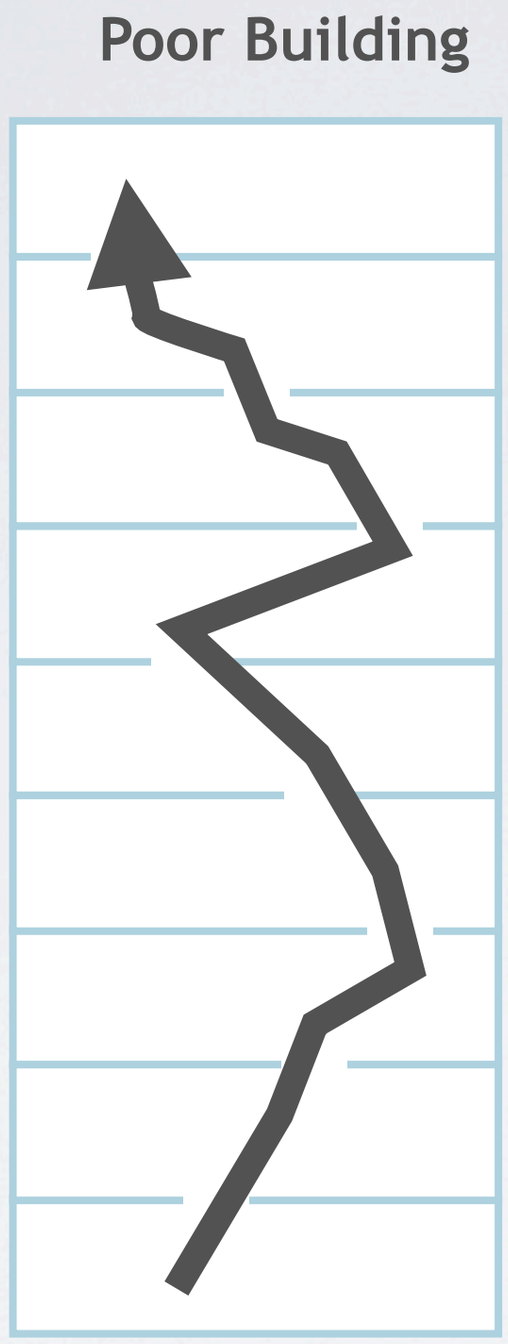

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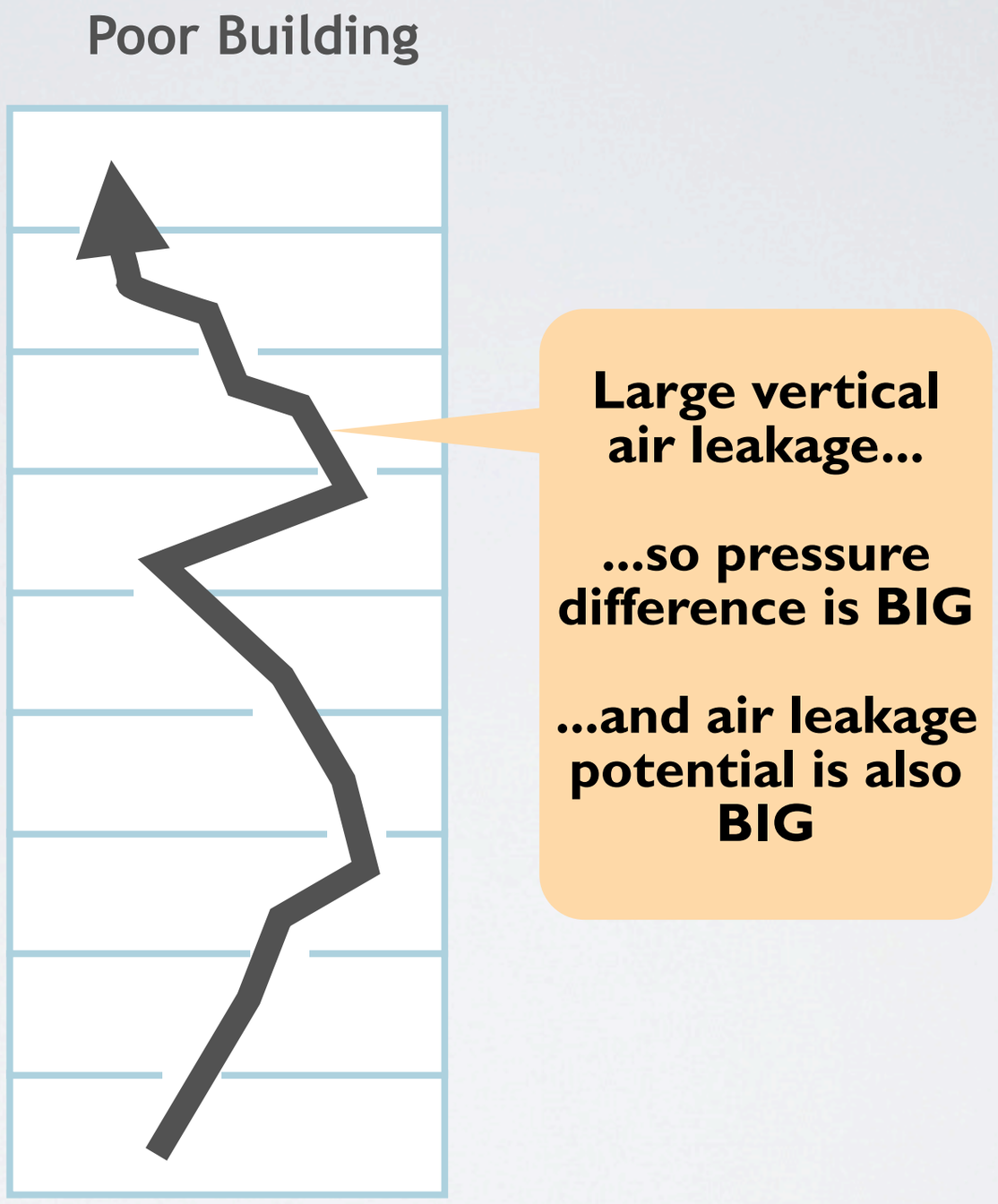

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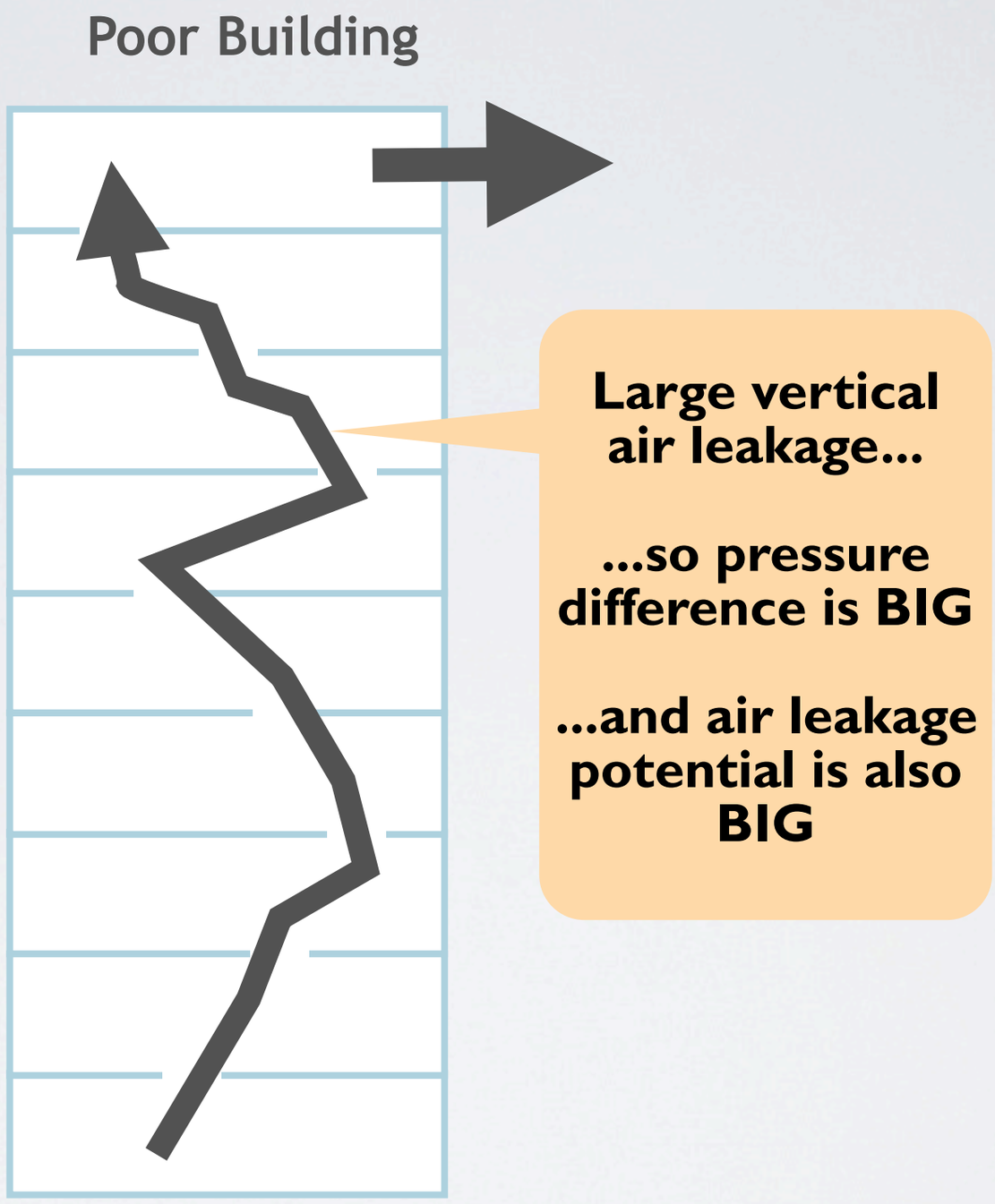

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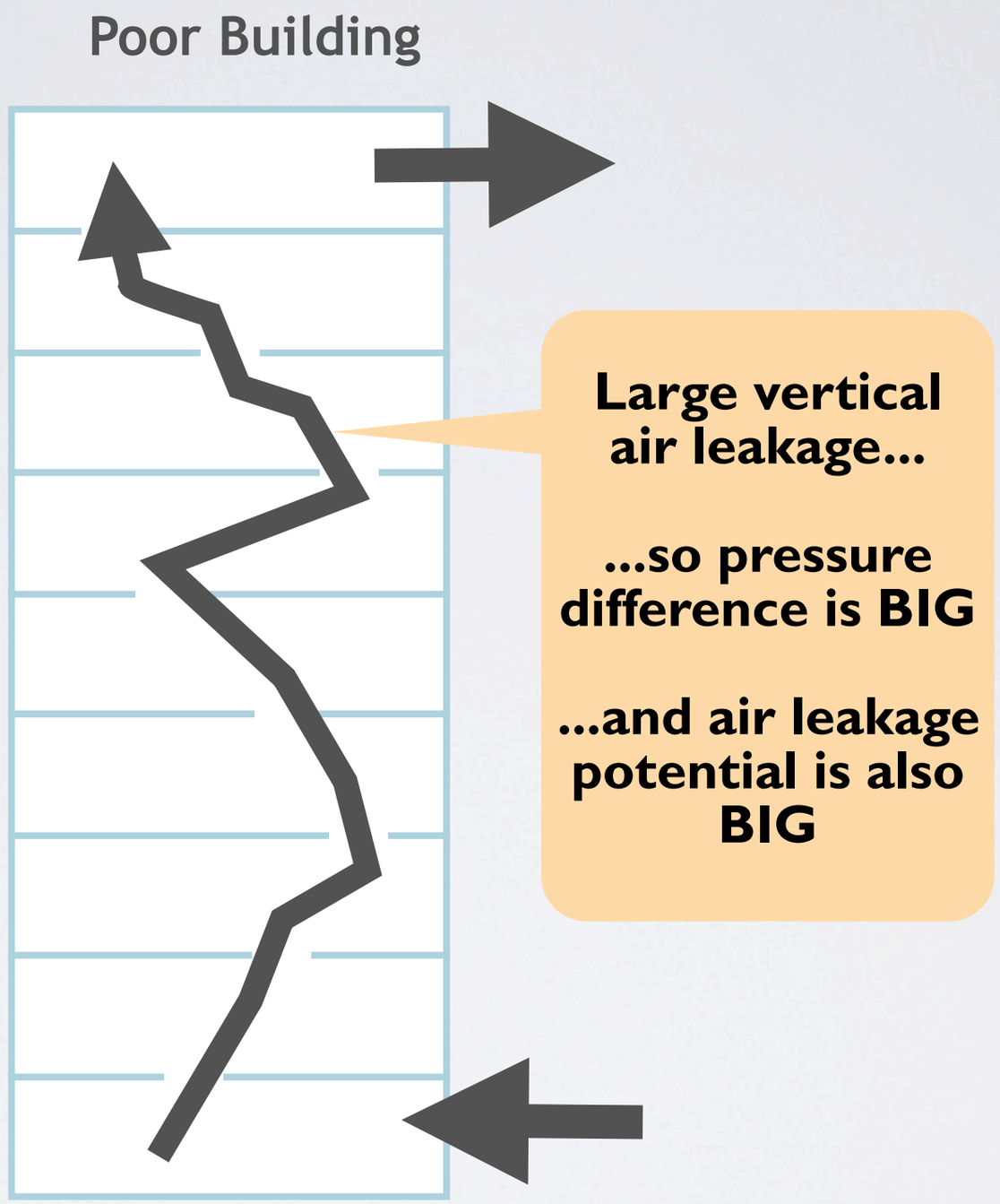

# Hot climate... stack effect is reversed. Cold air "falls out" at the bottom - Infiltration at the top, as in clinic case history

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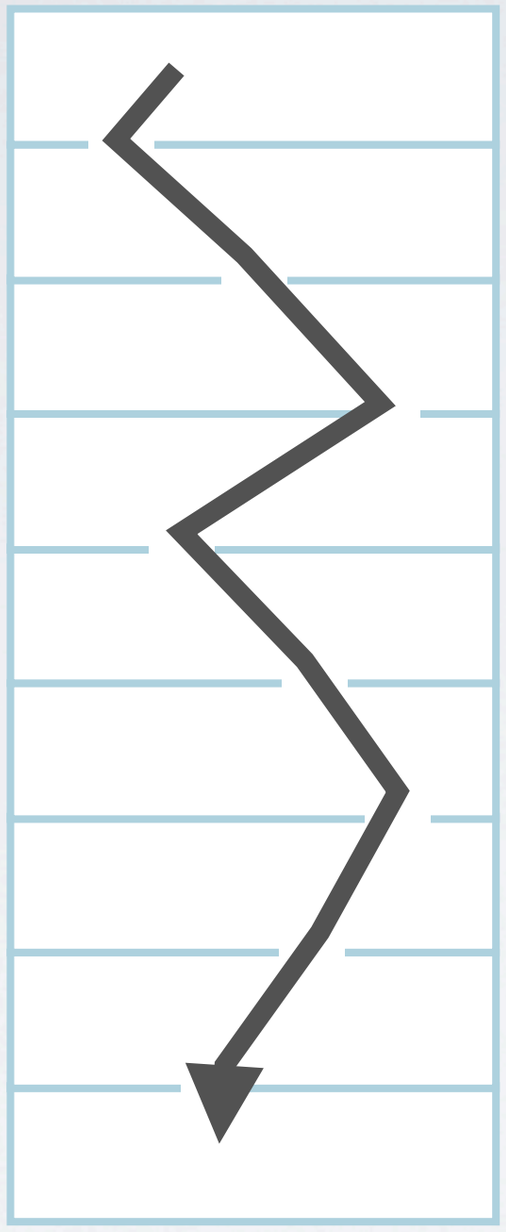

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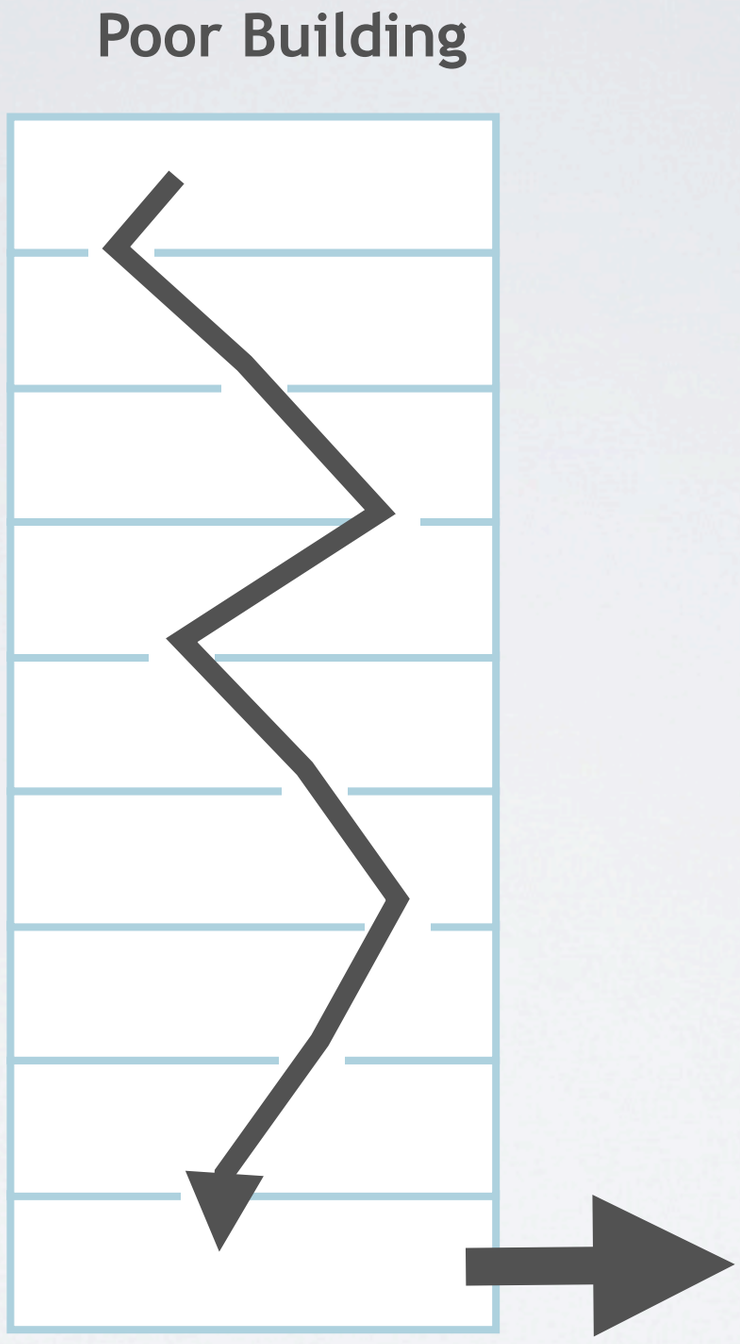

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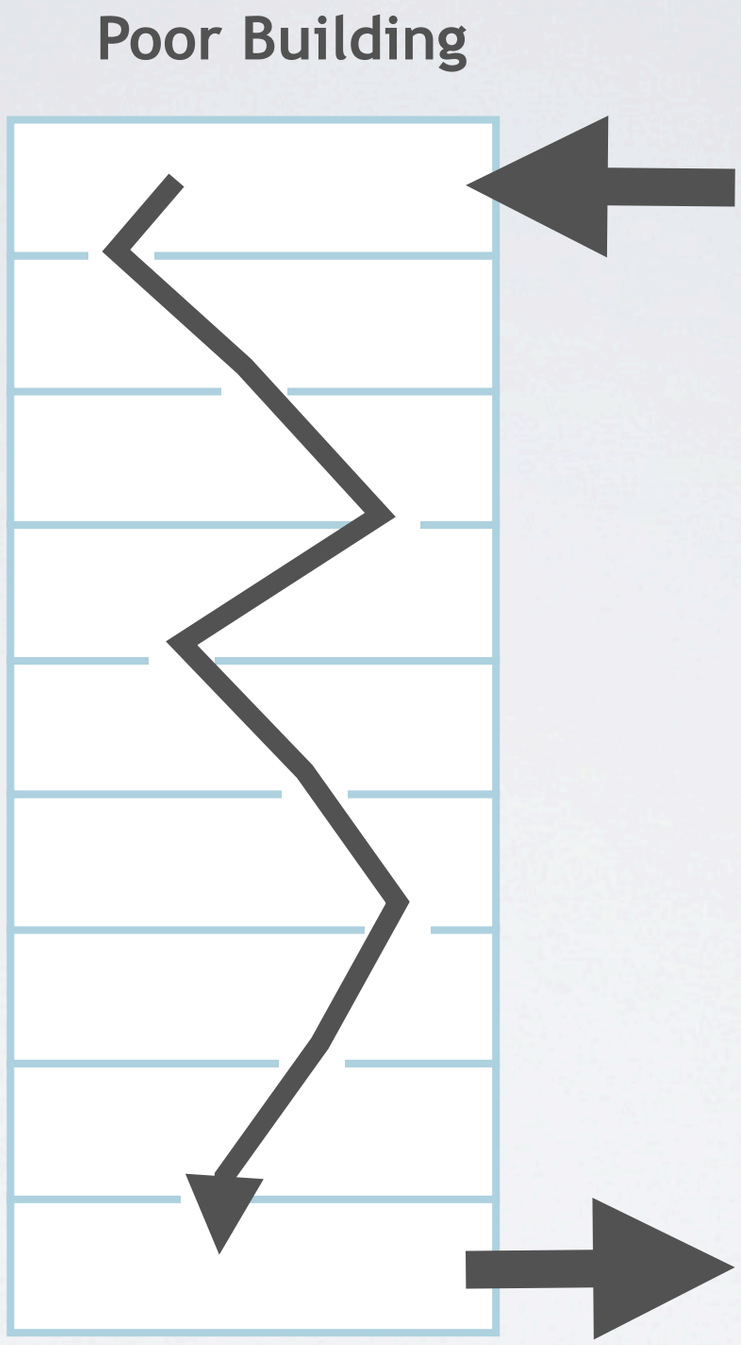

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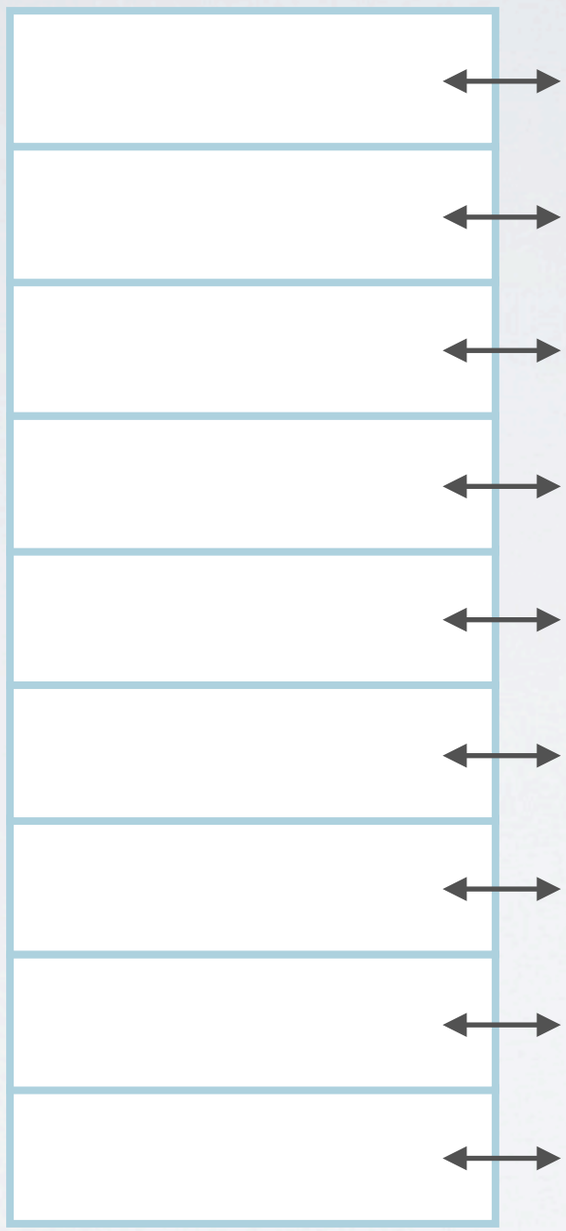

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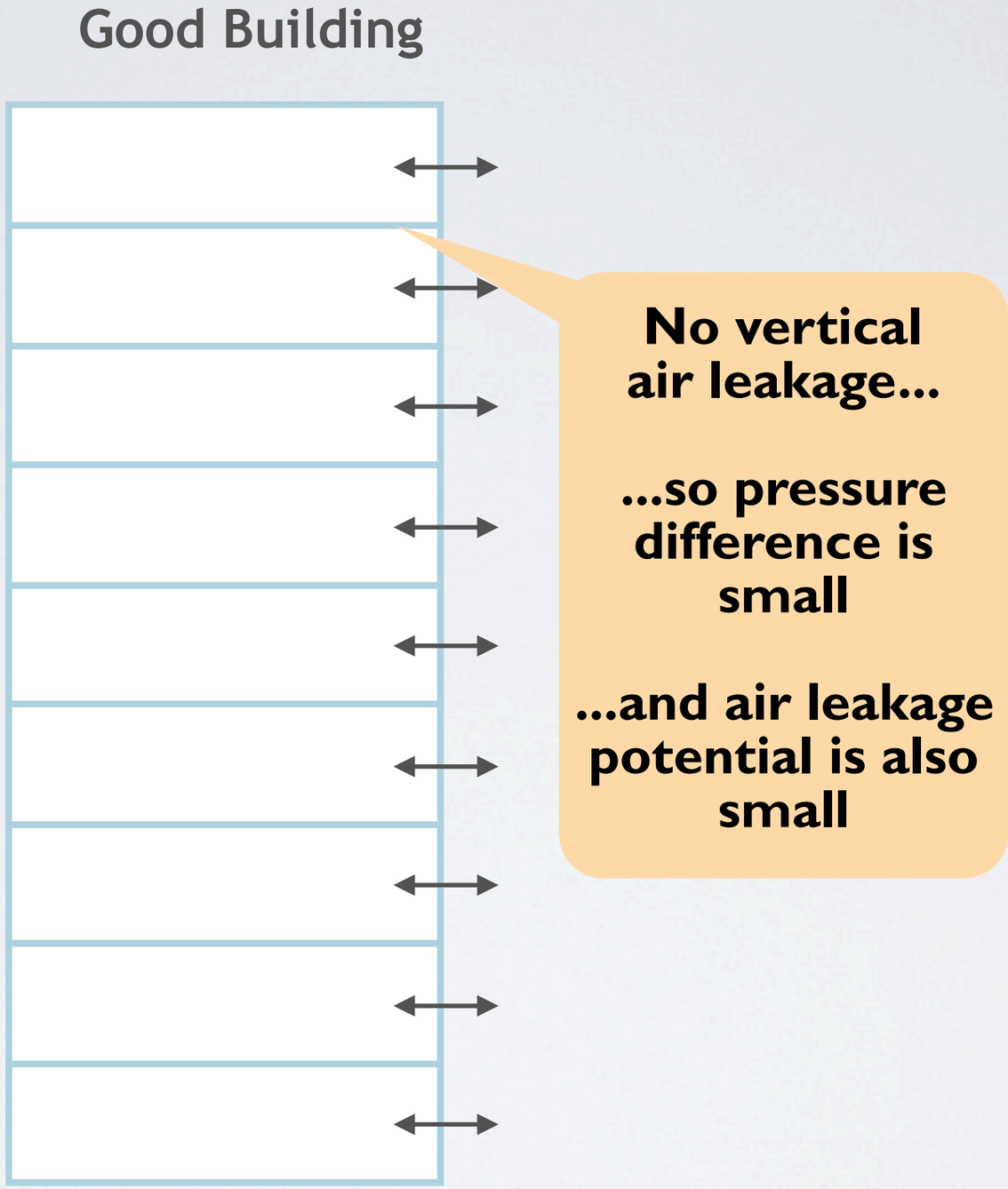
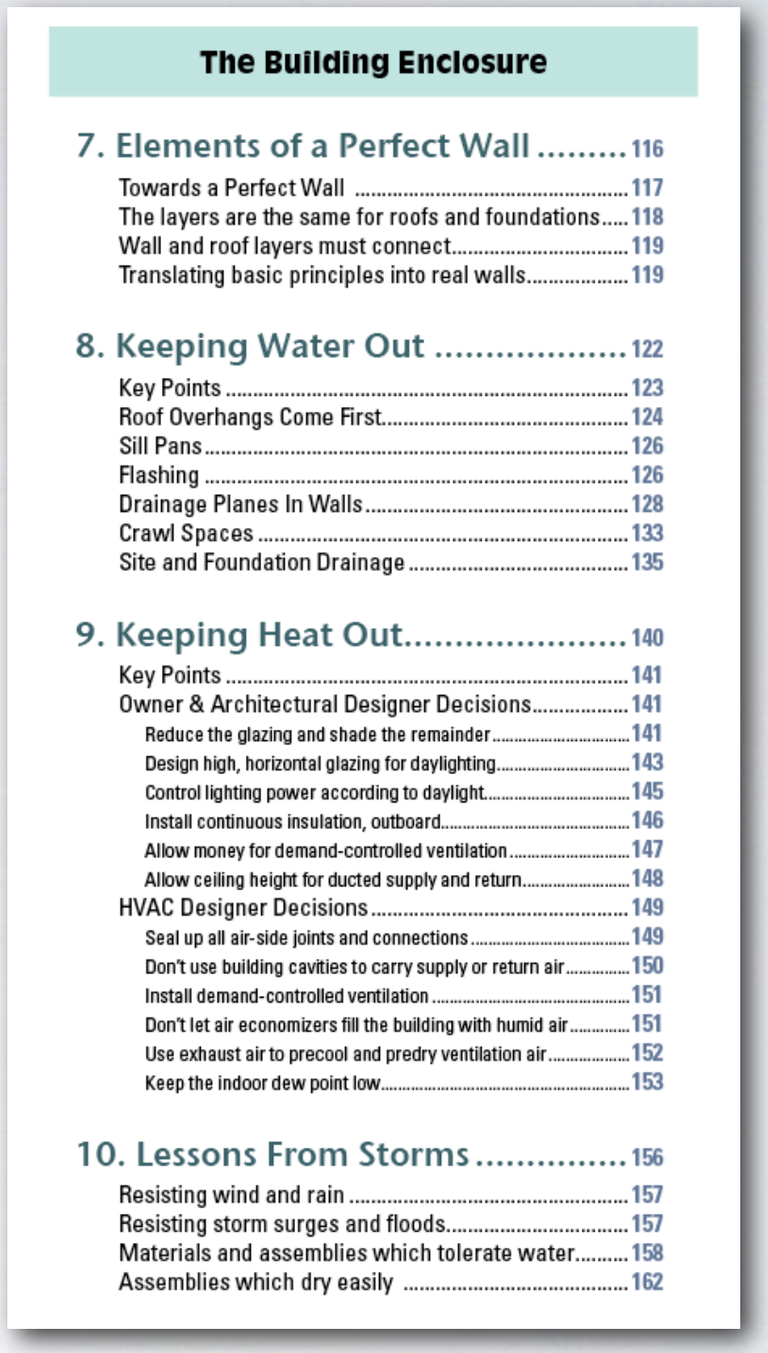


# Reason #3 - FIRE SAFETY



# Summary - Suggestions for architectural design



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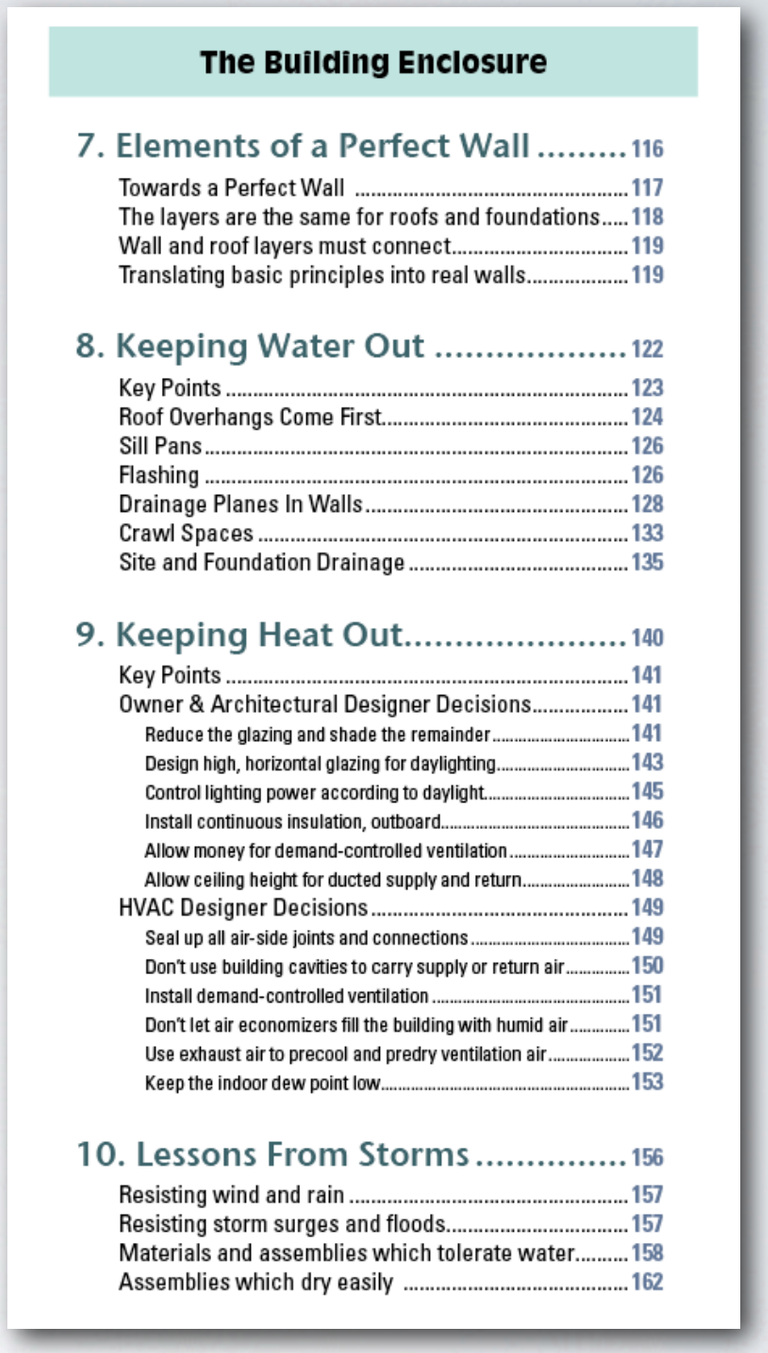
# Summary - Suggestions for architectural design

## 3 of My Favorite Suggestions:



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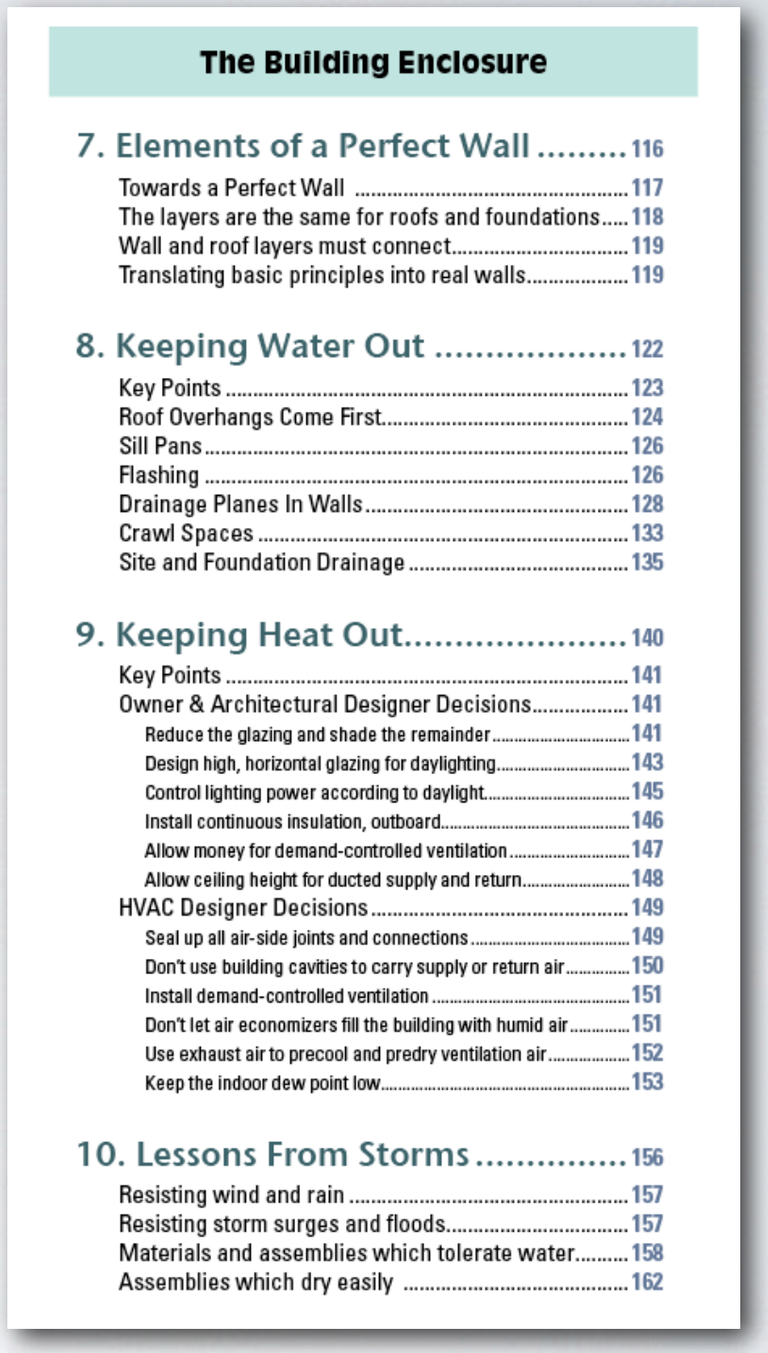
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.



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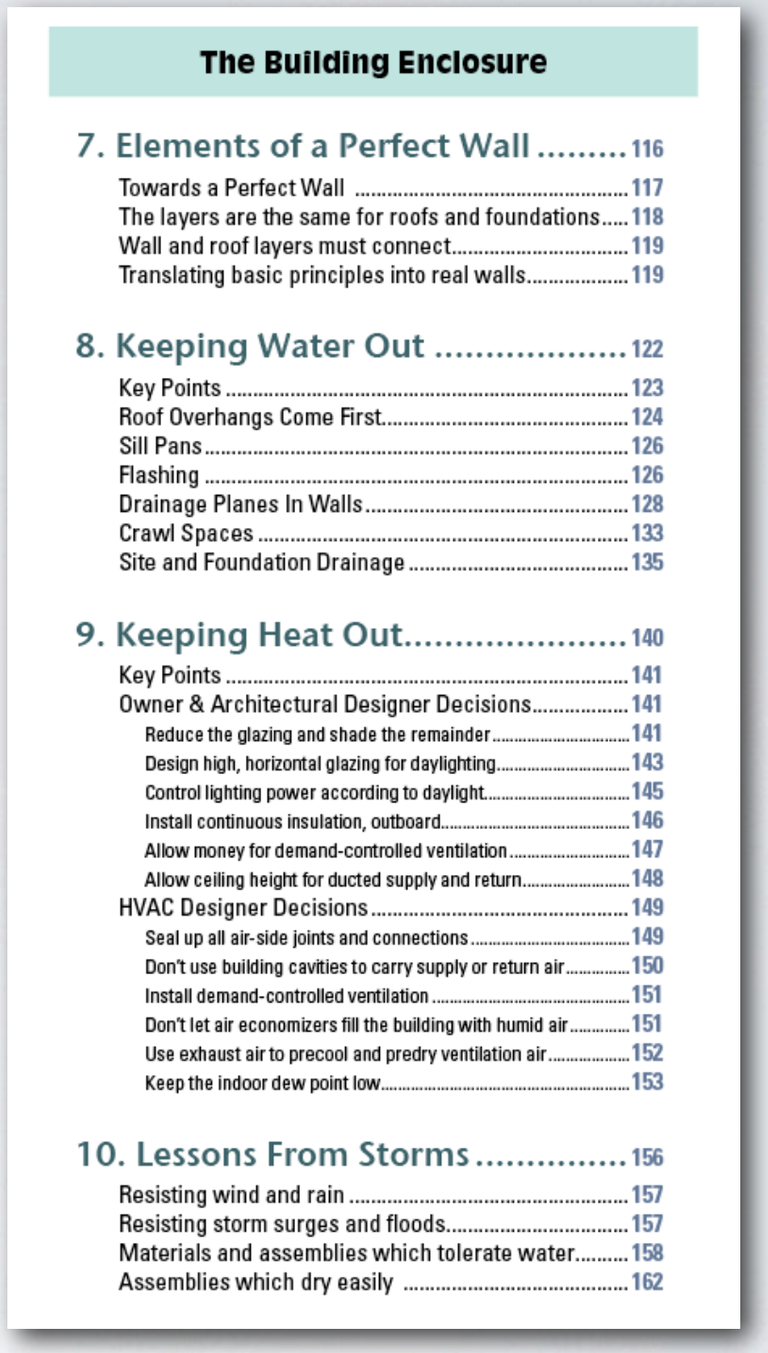
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.



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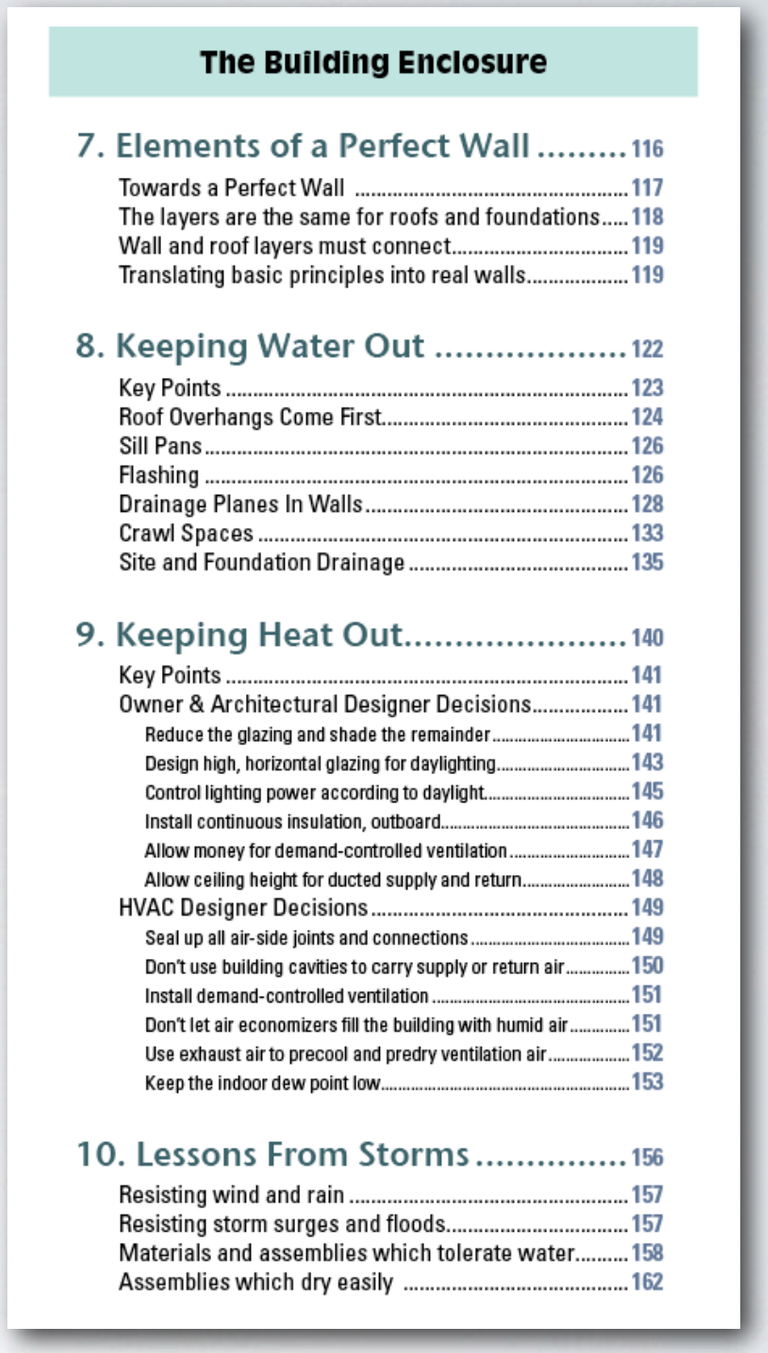
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.
- **Indoor insulation and air tightness**... For partly-cooled buildings.



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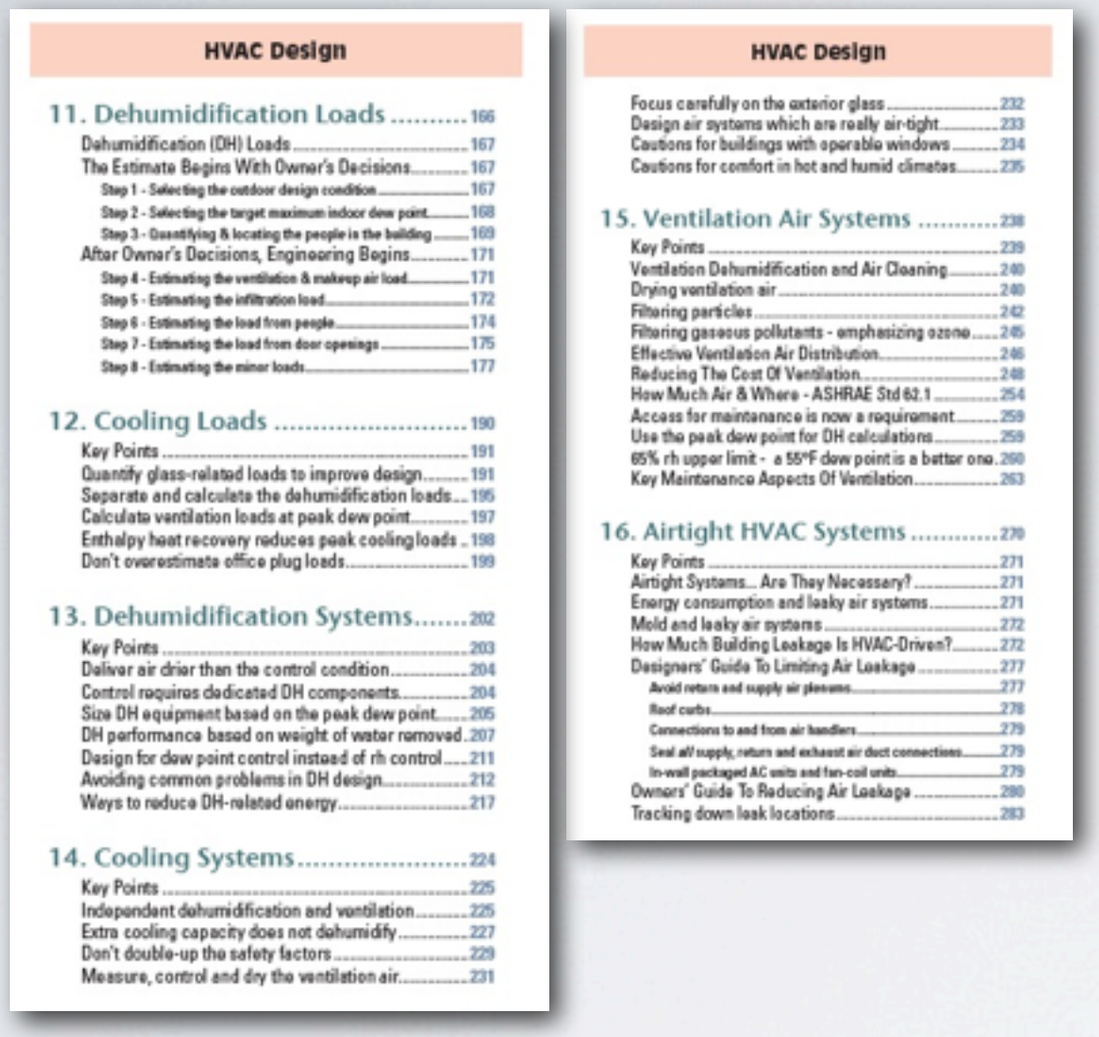

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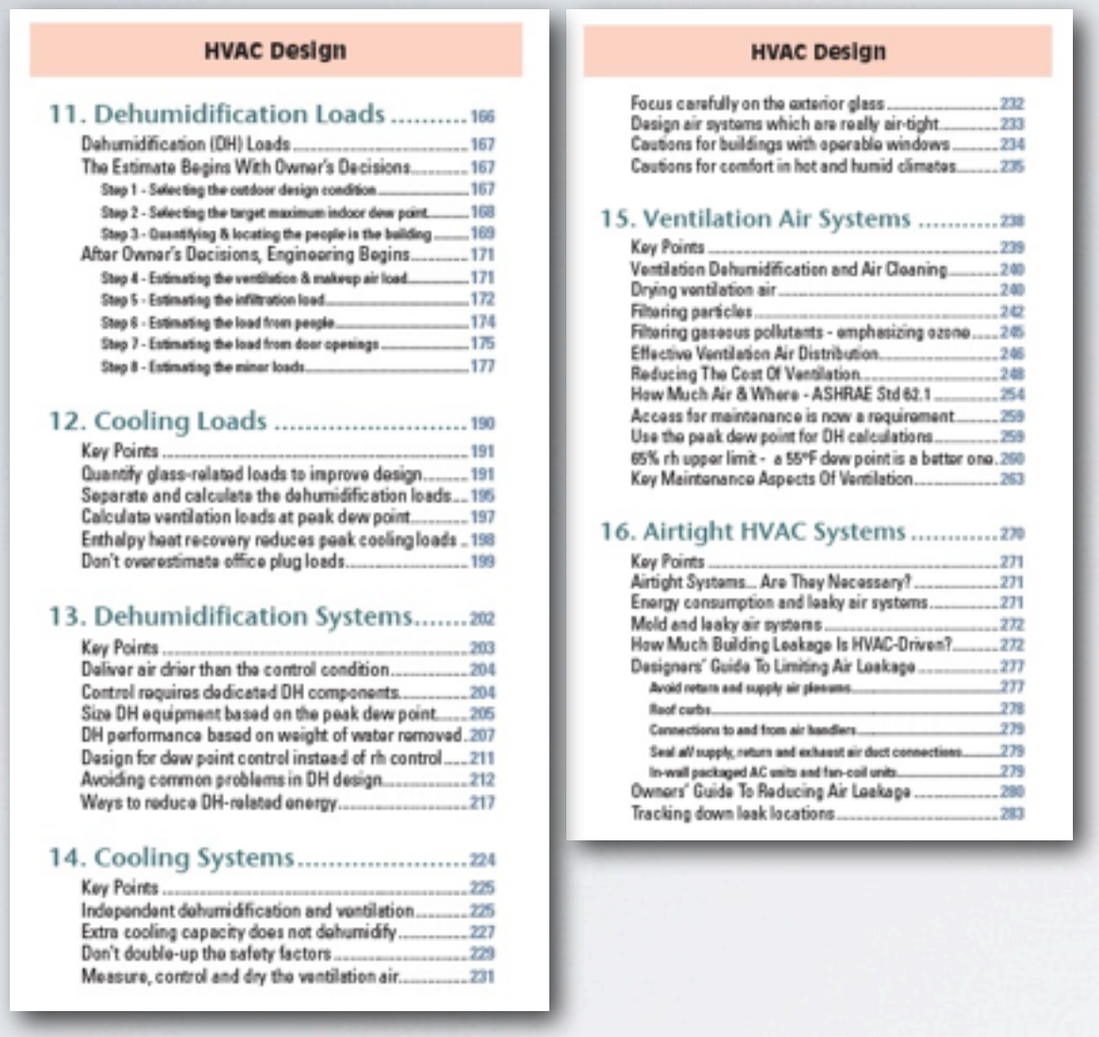

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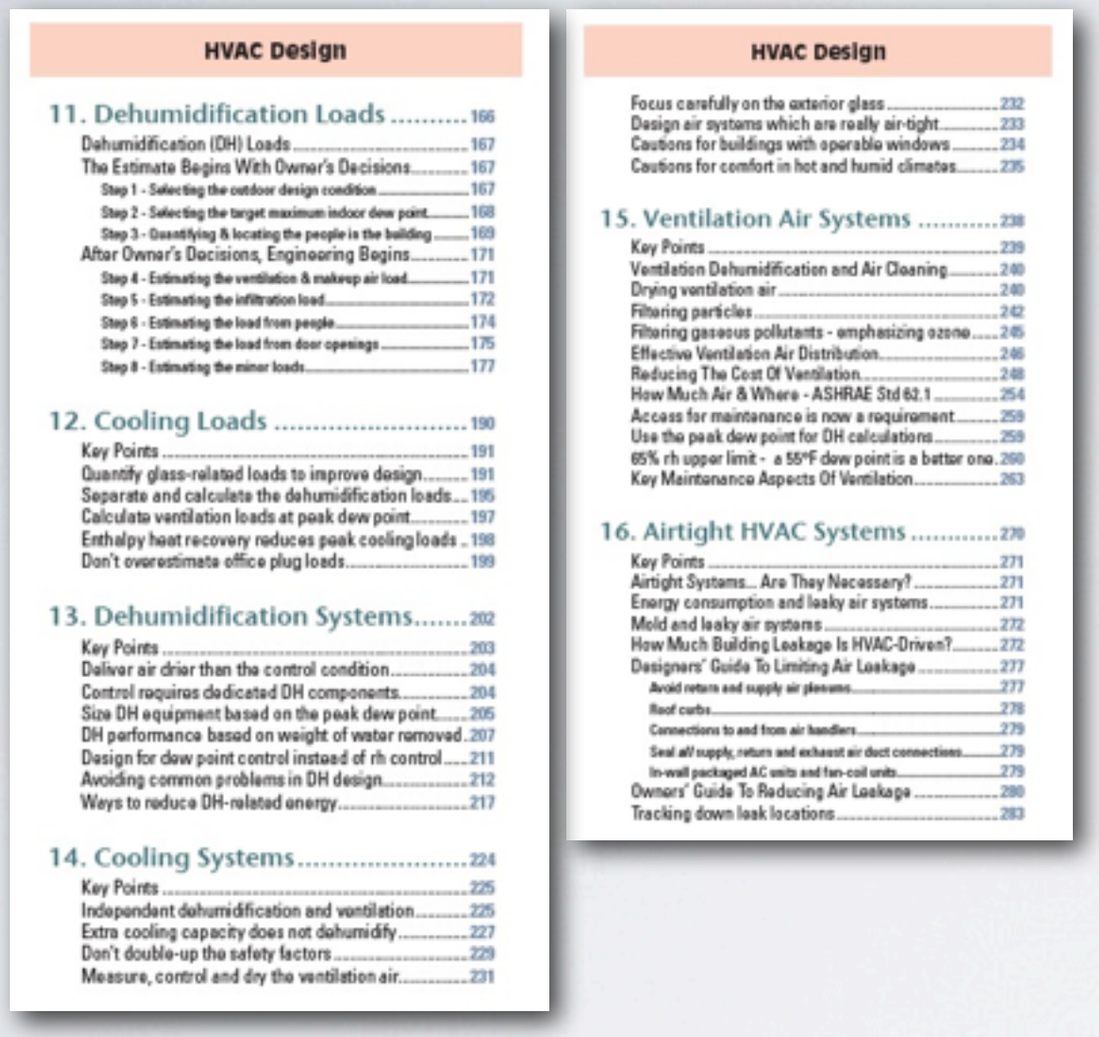

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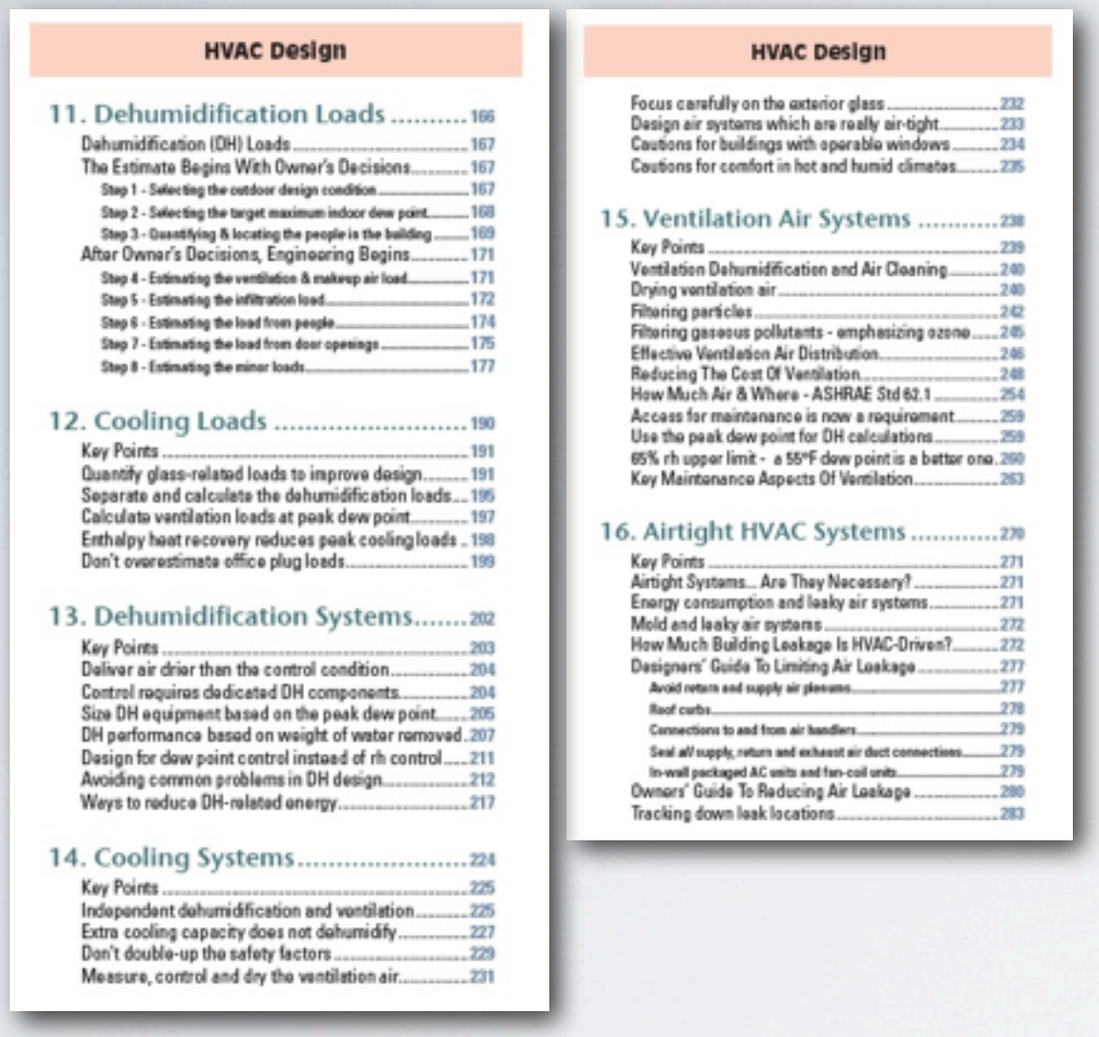

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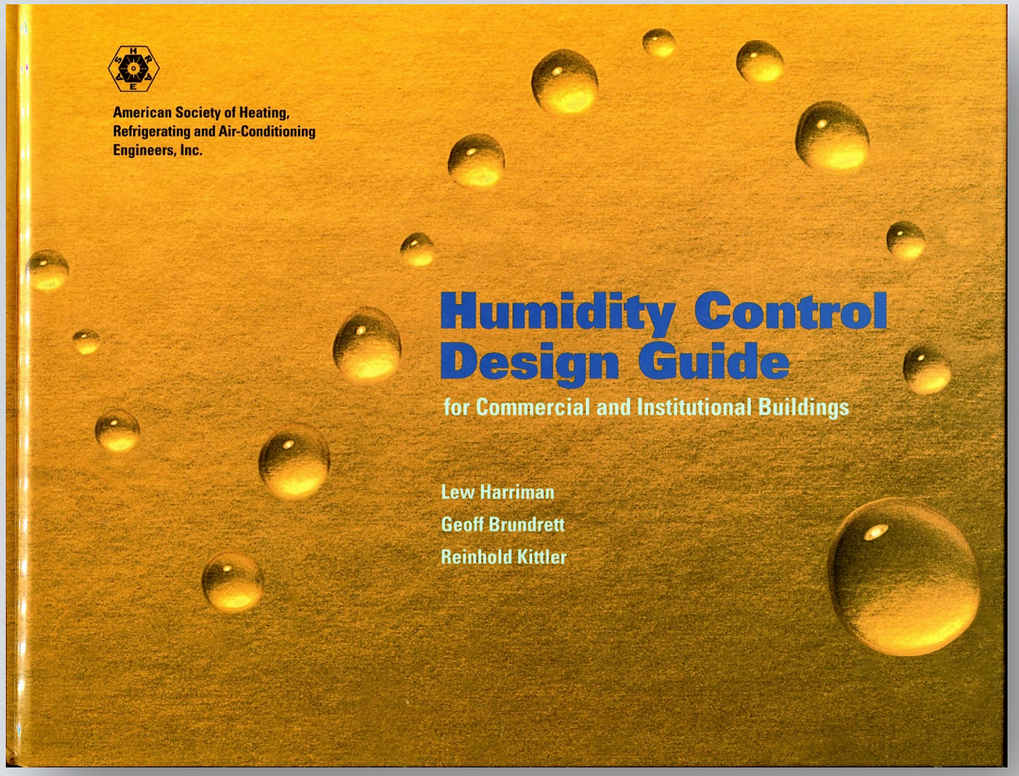
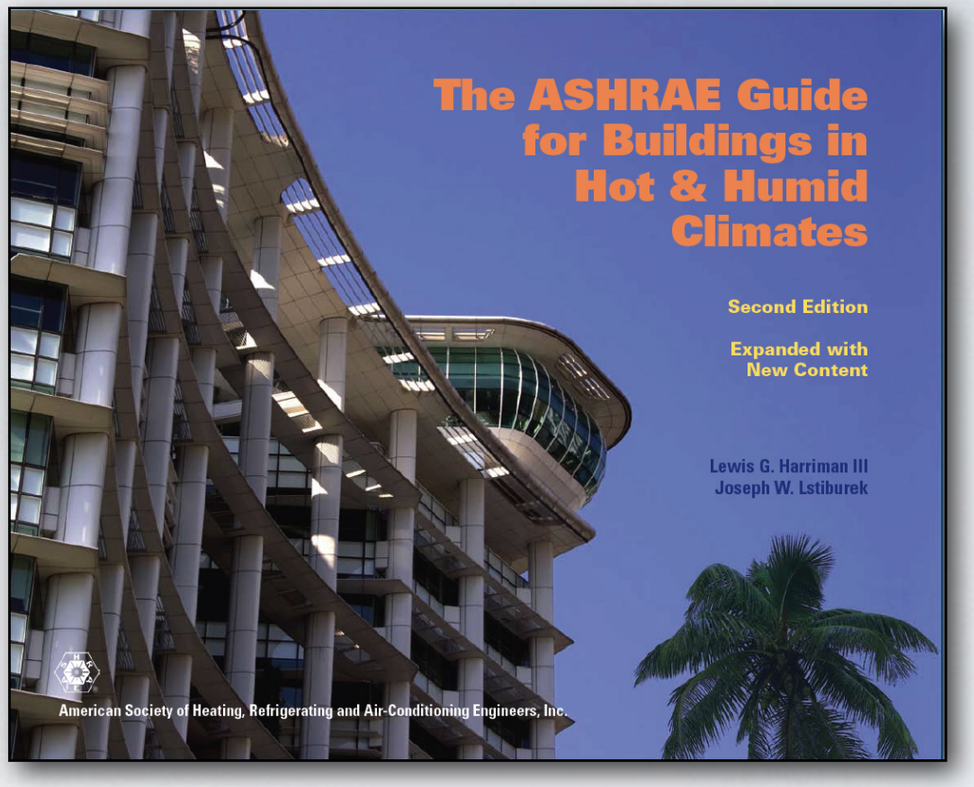
- **Dry, measure and vary the ventilation and makeup air at all times**... no more wasted energy and no flood of humid air.

- **Use ASHRAE peak dew point, calculate humidity loads and install a dehumidifier**... cooling tons do NOT automatically provide dehumidification.

# Further Resources



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2011 - 2013 Chair TC 1.2 - Moisture Management in Buildings
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## Singapore Chapter - ASHRAE Distinguished Lecture




- **Humidity Control Troubleshooting**
- **Humidity Control Design**
- **Suggestions for Buildings in Hot and Humid Climates**



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**What answers do you want.. before the end of the session?**

## Section 1 of 3

# Humidity Control Troubleshooting

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## 1. Introduction

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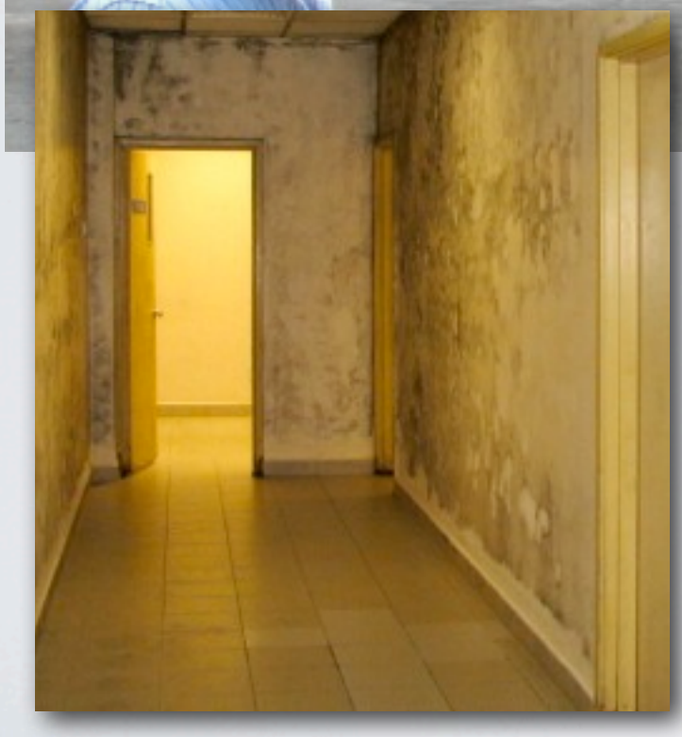

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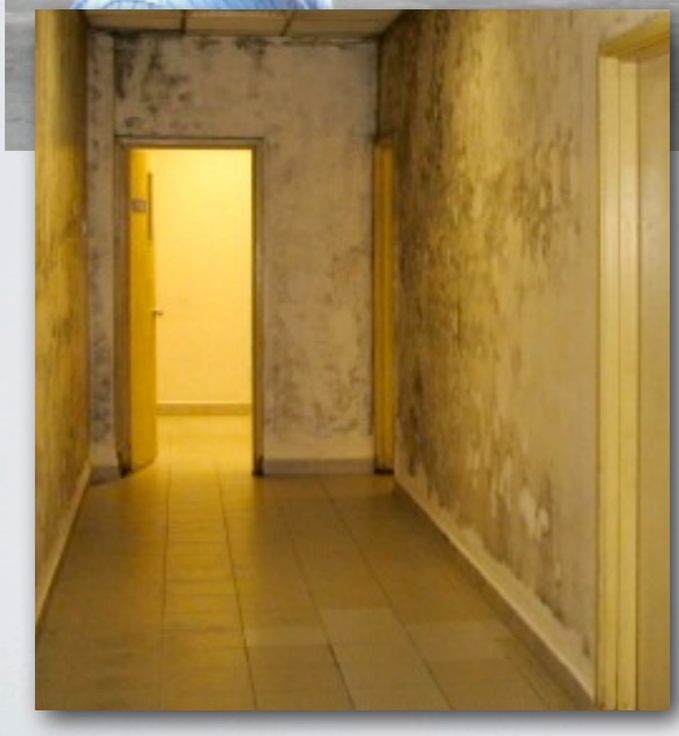



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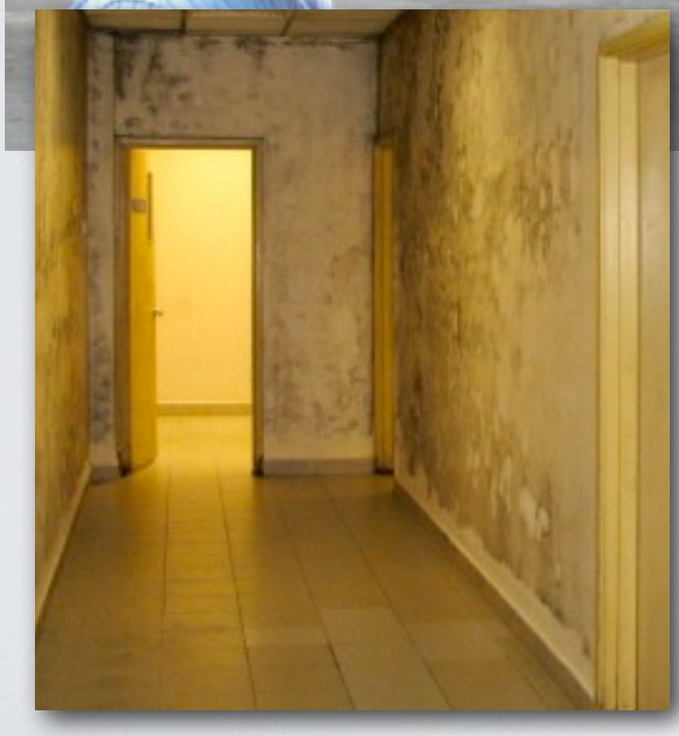





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- **NOT separate investigations for building and HVAC!**

# The voice of experience...
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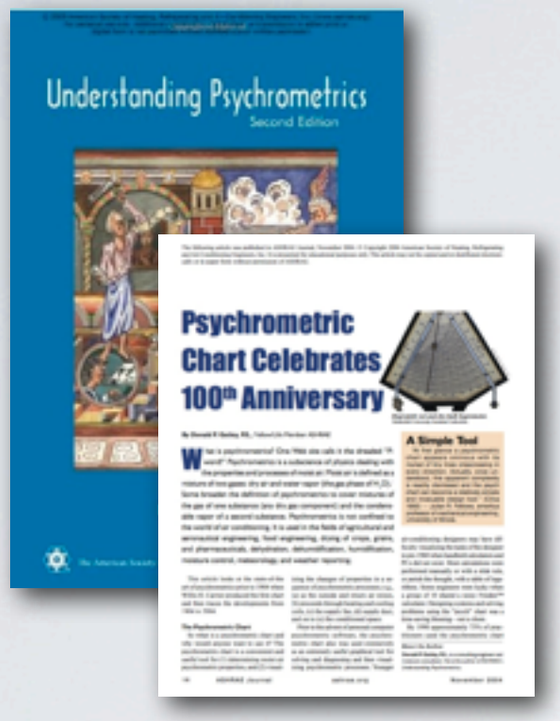


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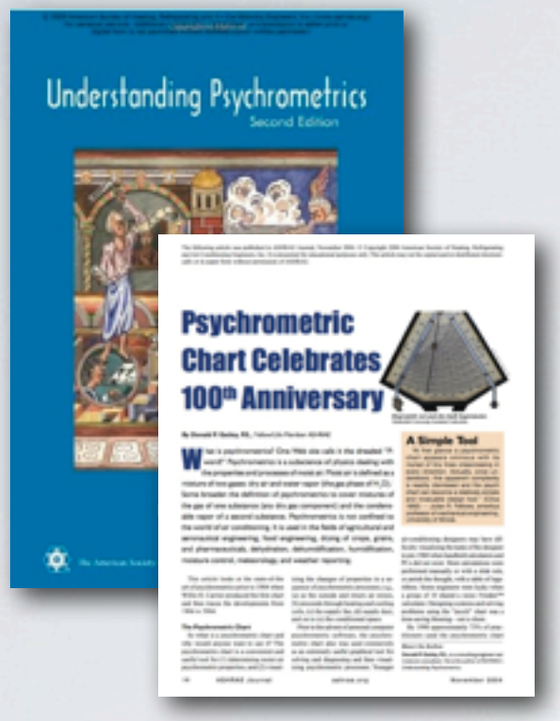


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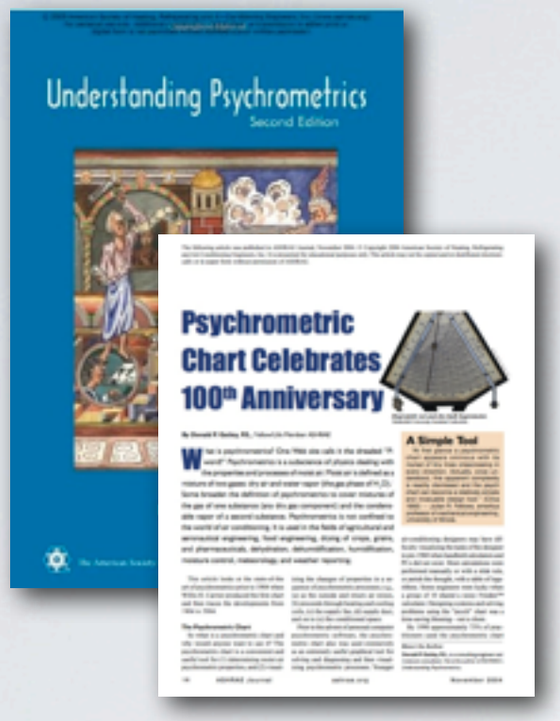


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**Don's advice: MOST HUMIDITY PROBLEMS ARE SIMPLE! Don't overcomplicate humidity troubleshooting. Make sure the building does not suck, and make sure the ventilation and makeup air is dry.**

# San Carlos Park Elementary School, Florida





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By Andrew C. Åsk, P.E., Member ASHRAE

# Ventilation and Air Leakage

Buildings leak water and air, which is normal and unavoidable. Therefore, designers should not fixate on preventing leakage, i.e., making buildings "airtight." Because even if all cracks were sealed, buildings have doors and windows.

Instead, the designer's goal should be to A) quantify leakage, B) reduce leakage if excessive, and C) control leakage by managing air pressures with the HVAC system. "Designer" in this case means at least two people—the architect and the HVAC engineer. It also may include the builder and building official. Until the building science engineer evolves as a separate discipline, primary responsibility for addressing building leakage will probably fall to the HVAC engineer.

A bicycle tire needs to hold air long enough to complete a journey in reasonable comfort, and lose no more air than can be replaced by the pump at hand. Although appearing airtight, the tire eventually will go flat. We should expect the same performance from the air barriers that help to form a building's pressure envelope.

So how much leakage is acceptable? The author suggests as a modest goal that buildings should leak no more than the air that must be introduced for acceptable indoor air quality.

The amount of outside air (OA) mandated by ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, is enough of a burden to the owner in terms of capital equipment cost and energy consumption. The owner should not need to provide even more OA to gain control of the indoor/outdoor pressure relationship.

**Building Pressurization**

Building air pressure with respect to outdoors should be neutral so that doors open and flue-gas vents function properly. However, should buildings be slightly positive or slightly negative? Most building scientists and mold remediation professionals now believe that wall and roof constructs should be pressurized from the cooler, dryer side. Dry air (with respect to the negative side) migrating through the wall absorbs moisture and tends to dry out the interstitial construction. Conversely, if hot, humid air is allowed to migrate through the construct, it can cool below its dew point and create condensation in the interstitial space, damaging building materials and allowing mold to grow.

With this principle in mind, buildings experiencing hot, humid weather should be positive with respect to the outside, and buildings in cold climates can be slightly negative. Experience has shown that designing for a very small pressure differential, (less than 0.01 in. w.c. [2.5 Pa] works well in hot, humid climates.

Wind currents will override pressurization this small. However, as wind shifts direction, it tends to cancel out its effects upon pressurization. This does not hold where one strong, wind direction prevails, such as by the sea. Cold climates will require a greater pressure differential, primarily due to stack effect.

"Leakage" in the natural, unplanned and uncontrolled flow of air into (infiltration) and out of (exfiltration) buildings. The artificial, intentional, controlled (hopefully) flow of air into buildings is called ventilation or outside air; the corresponding outward flow is exhaust. These intentional flows must work in concert with natural leakage.

The relationship between OA, exhaust, and leakage can be expressed with simple arithmetic:

**Building Positive, Hot, Humid Climate:**

Outside Air = Exhaust + Leakage (Exfiltration)

**About the Author**
**Andrew C. Åsk, PE.**, is an HVAC and IAQ consultant in Cape Coral, Fla.



> "Until the building science engineer evolves as a separate discipline, primary responsibility for addressing building leakage will probably fall to the HVAC engineer."

1.0 ACH cfm = V/60

Then, based upon the practitioner's experience, estimate an infiltration rate in terms of a fraction of ACH. The author, for example, has allowed between 0.50 and 1.0 ACH for "infiltration" throughout his career with reasonable success. Post-1973 buildings built to ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, requirements might be as tight as 0.25 ACH. Antiquated factory buildings on the other hand could experience 2 or more ACH.

Why did I use between 0.50 and 1 ACH? Because my HVAC professor at Iowa State told me to in 1962. All I had to go on was his direction, *Manual J*, and one tattered ASHRAE Handbook shared by the entire class. I had no need to question my assumption until 25 years later, when I was unable to heat a factory in Fargo, N.D., which had fenestration that had not been fixed for the past 55 years — its air apparently changed three times each hour. A few years later, I found that I couldn't dehumidify buildings in southwest Florida. I suspected there had to be better ways to estimate building leakage. There were.

Air change rates (ACH) continue to be a good way to express building leakage, but coupled with a pressure differential, normally 0.20 in. w.c. (50 Pa). A building would never operate (intentionally) at this pressure, but they can be more accurately tested at this high pressure (for the same reason that a damper or valve must experience a high-pressure differential before it can provide close control). The ACH rate at 0.20 in. w.c. (50 Pa) is interpolated to the actual building pressure desired (say 0.01 in. w.g. [2.5 Pa]) to determine how much air will be required for pressurization. The astute HVAC engineer should begin to see a relationship that looks like a constant mechanical duct system whose behavior can be predicted by

**Building Negative, Cold Climate:**

Outside Air = Exhaust – Leakage (Infiltration)

HVAC engineers can readily calculate how much outside air is required for acceptable ventilation as prescribed in Standard 62, and how much exhaust is required for toilets, showers, hoods, etc.

Building leakage is a bit more elusive. The goal of this article is to discuss the methods for measuring and expressing leakage, and to report the results of a case study, San Carlos Park Elementary School, in Ft. Myers, Fla.

**Quantifying and Expressing Leakage**

Perhaps the oldest (and worst) method for estimating building leakage was the "crackage" method, where the width of cracks around windows and doors was estimated, a cfm per linear foot of crack allowance assumed, and infiltration estimated by extending these computations.

A better (and certainly much easier) method is to begin by computing the volume of a building in $ft^3$ and then divide that number by 60 as an expression of the cfm airflow required to "change" the air in an hour's time (ACH):



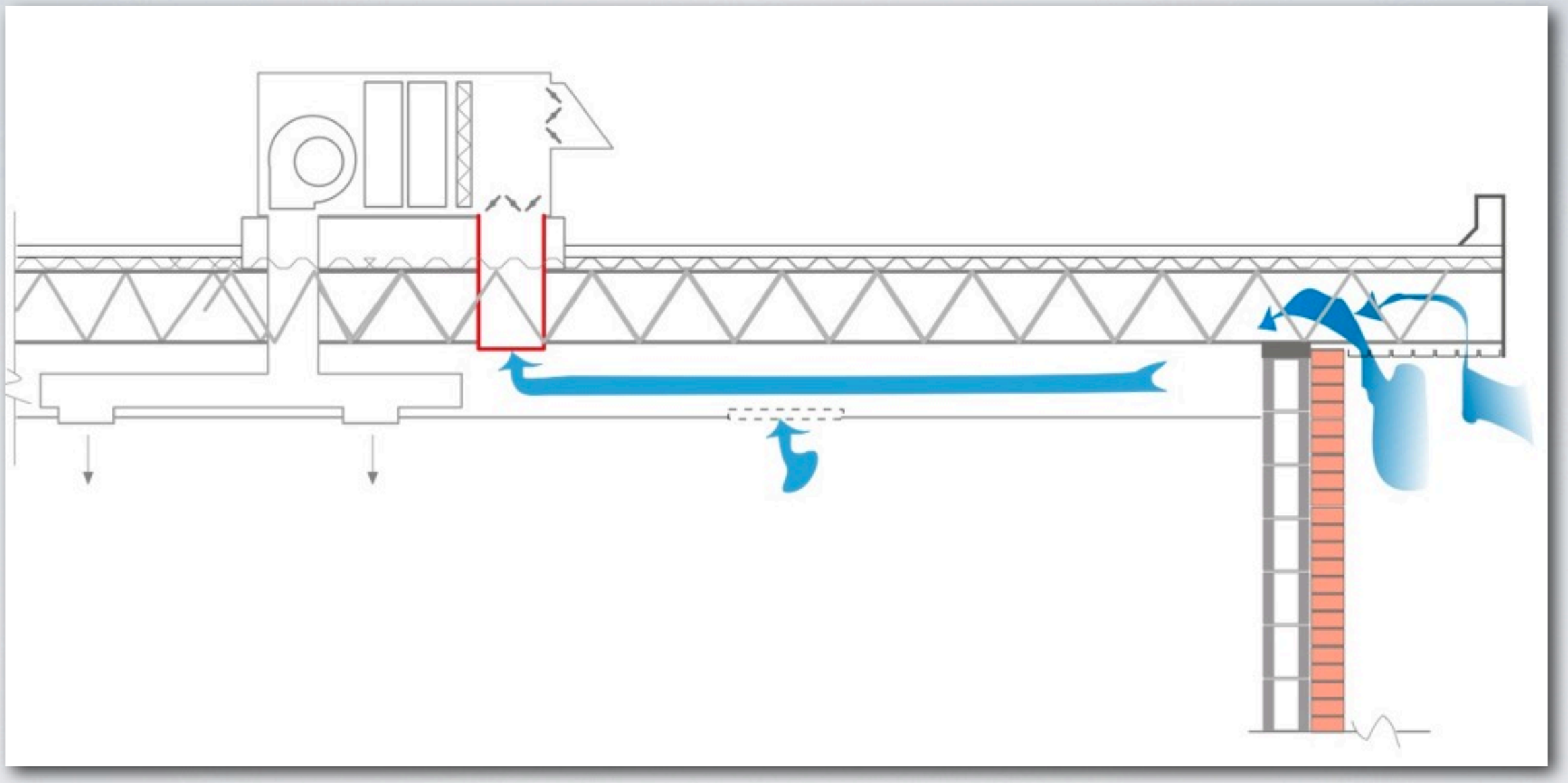
Andy Åsk - ASHRAE Journal - November 2003

# Problems



- "Poor indoor air quality" (moldy odors)
- Comfort complaints - damp and muggy
- AC system can't maintain temperatures
- High energy costs

# Low-cost HVAC design - Return air plenums



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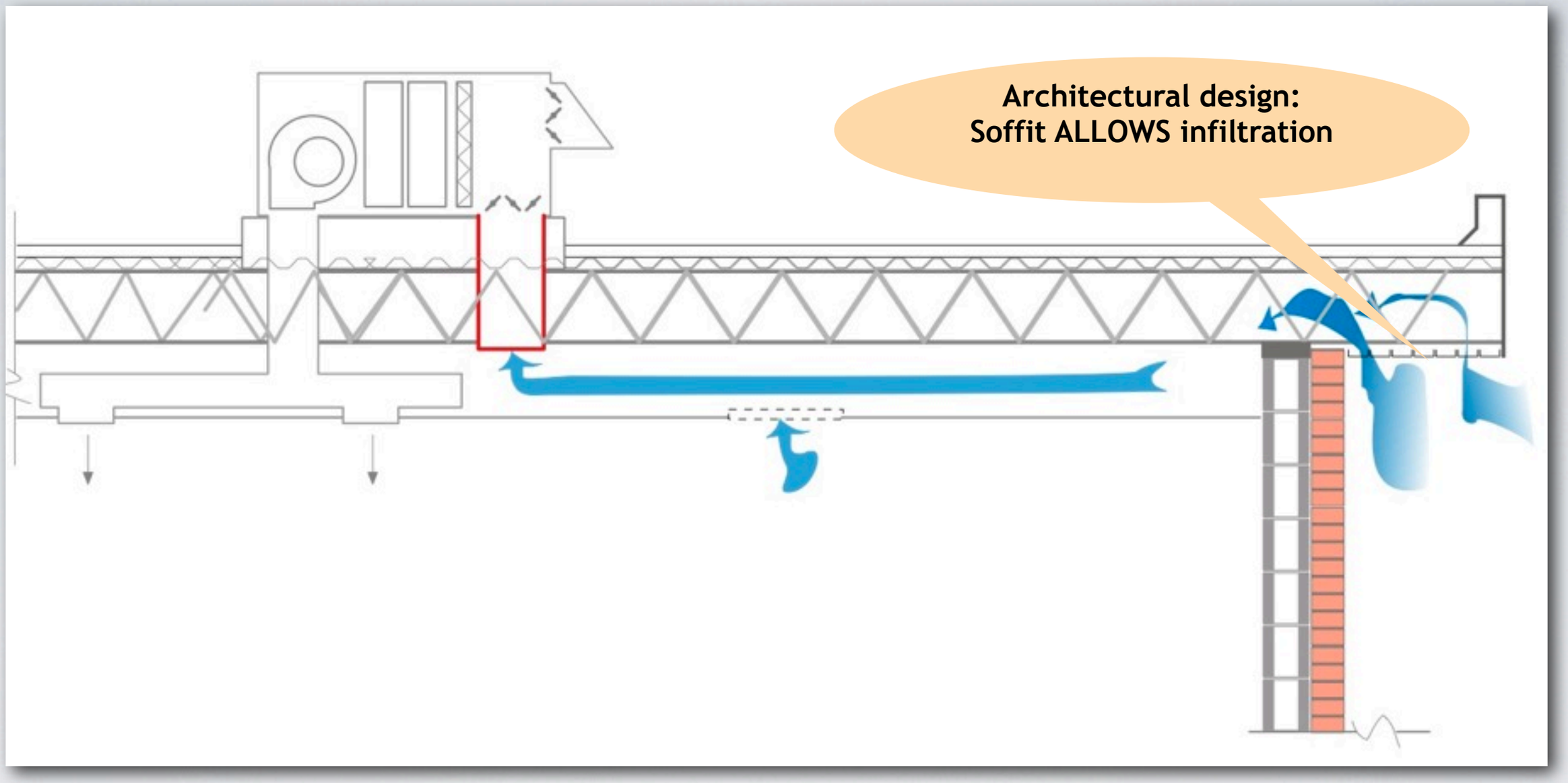

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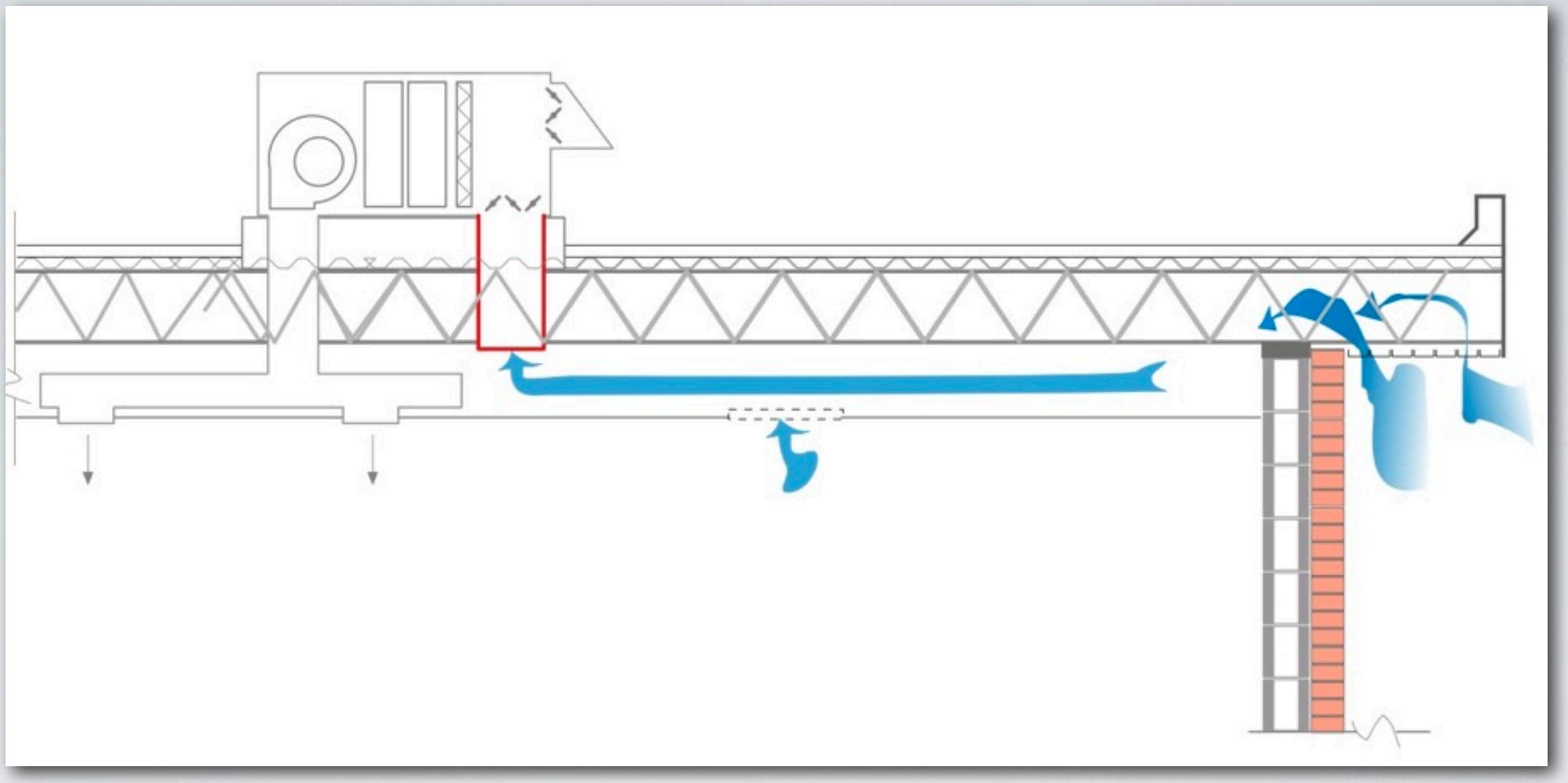

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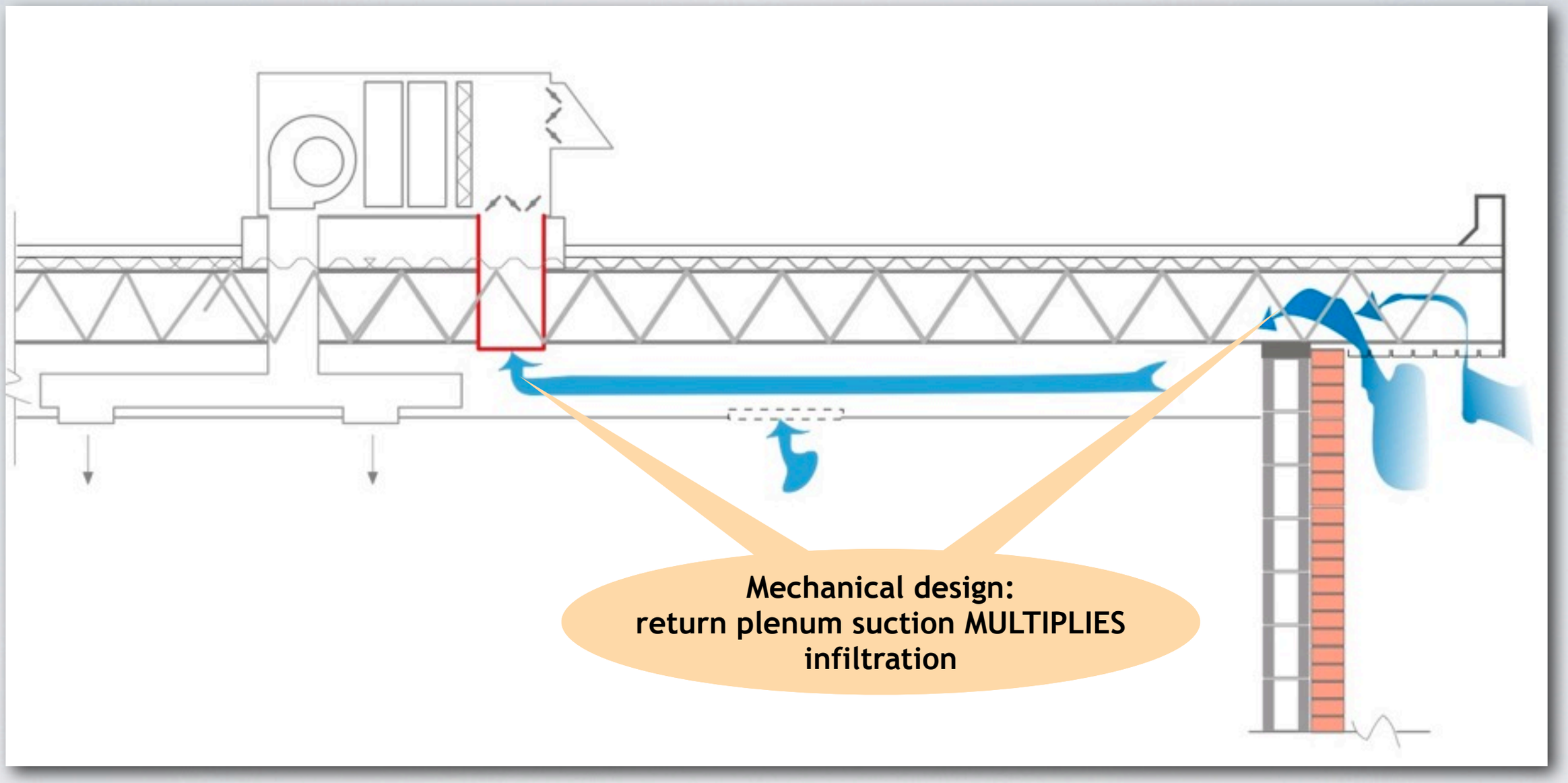

# Architectural and HVAC shortcomings combine to cause big problems

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| **Before Remediation** | 7,300 cfm | **408** | 42,000 cfm | **2,349** |

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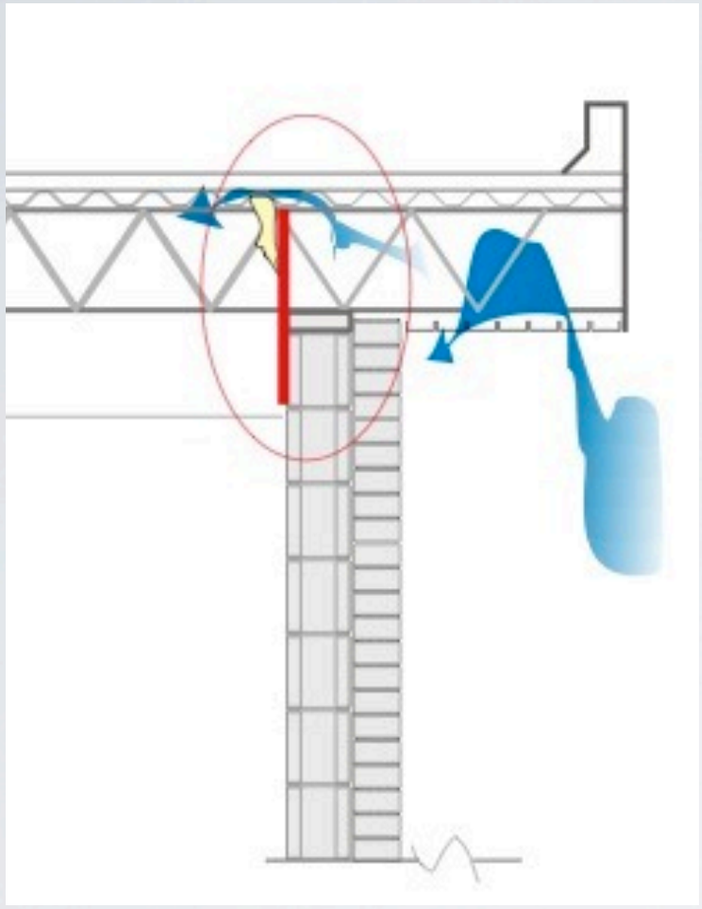
**Note the SIZE of the unexpected load when systems ARE operating...!**

# Retrofit Solution



- Added gypsum board between the wall and roof deck.
- Sealed the gypsum board to the roof deck with spray foam to avoid labor-intensive cutting and fitting.
- Protected spray foam with a layer of spray-on intumescent, fire-rated sealant
- Net result... 55% reduction in passive (system off) air infiltration

# Troubleshooting Sequence and Procedures

1. Traditional troubleshooting procedures, with a brief example of why they do not work.

2. The essence of humidity control troubleshooting - Loads vs. DH capacity

3. Troubleshooting sequence and procedures
   a. Investigate and understand the problems
   b. Measure the loads
   c. Measure the DH capacity
   d. Understand the controls
   e. Plan the solution

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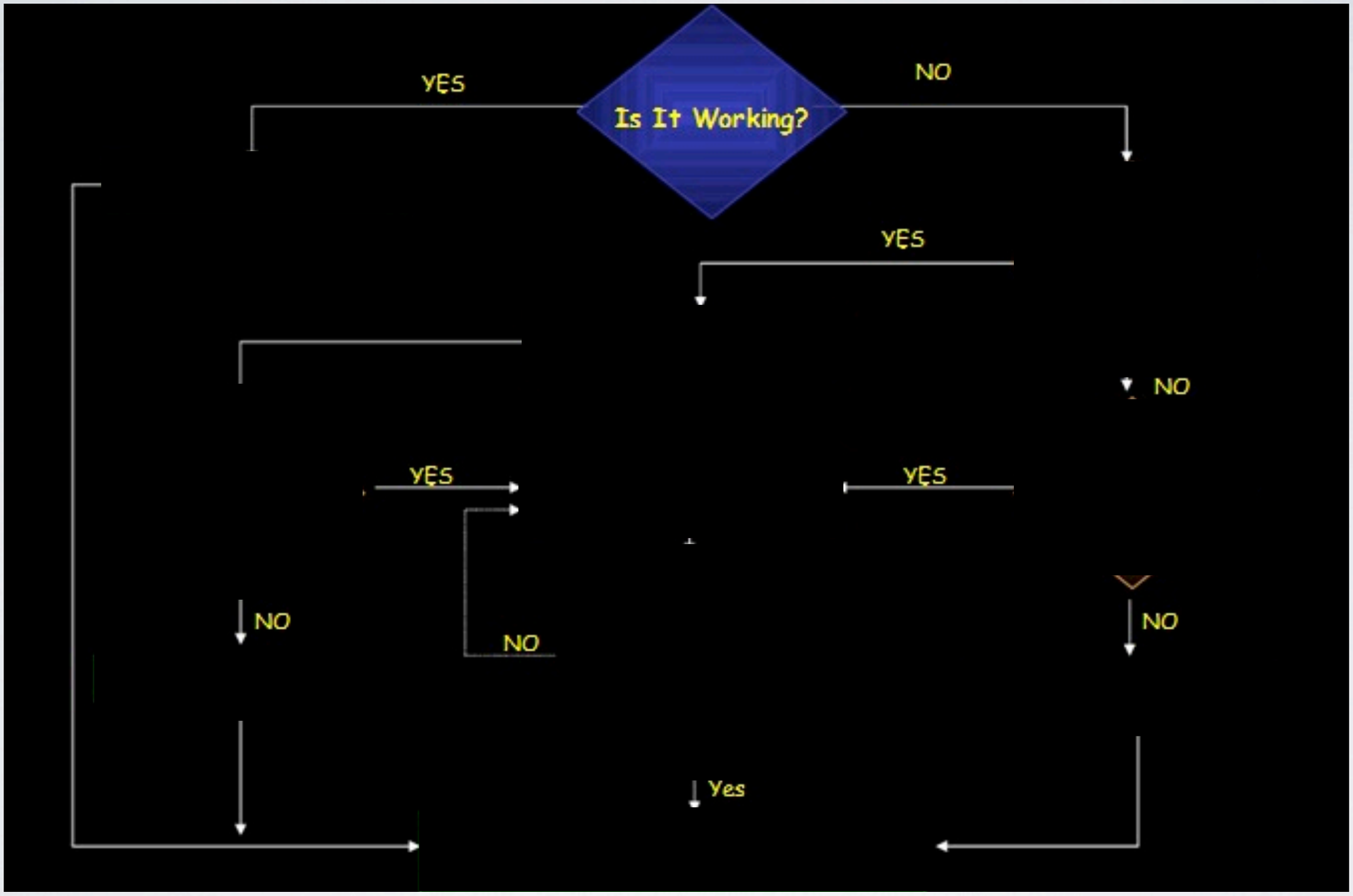

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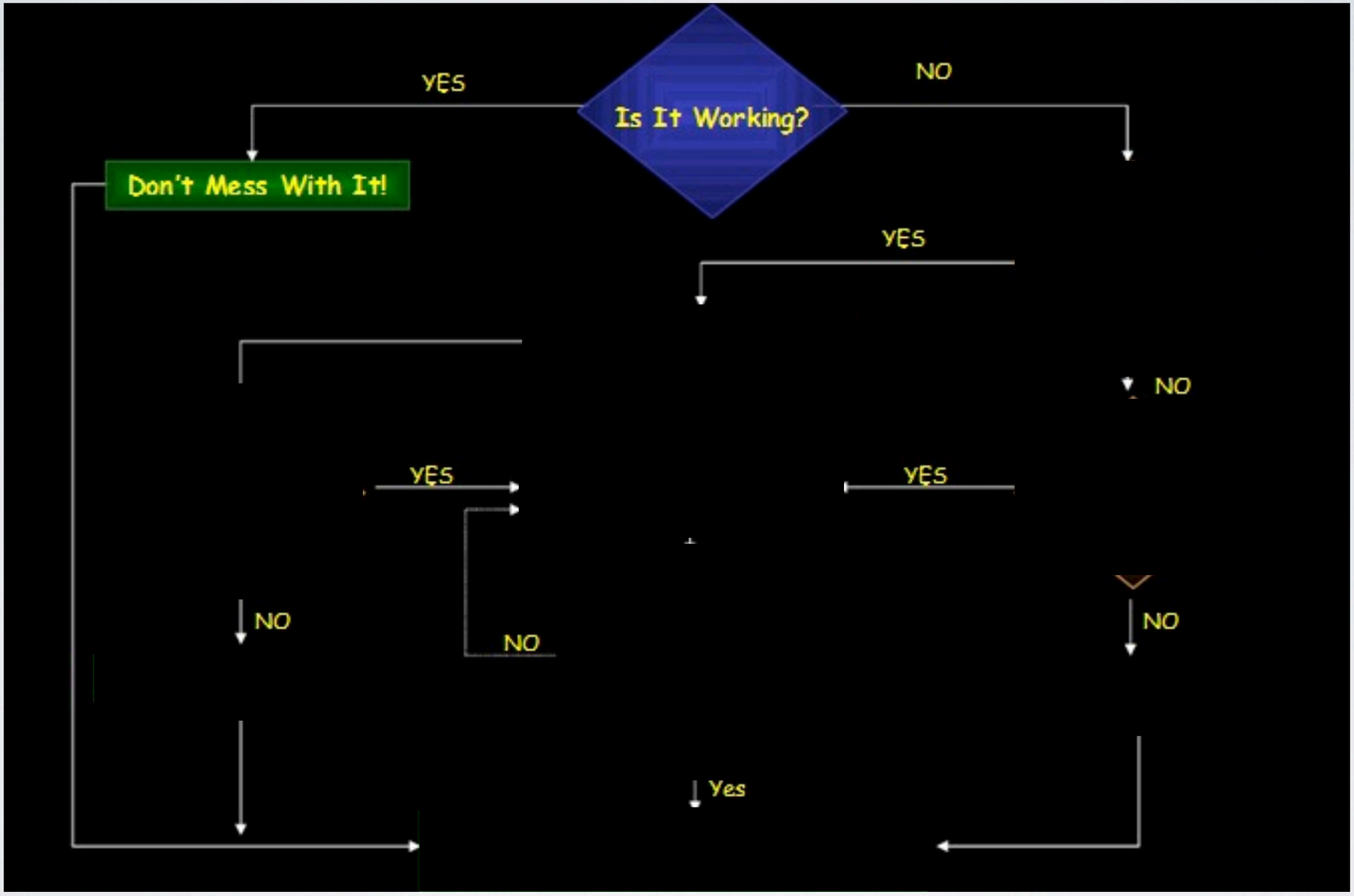

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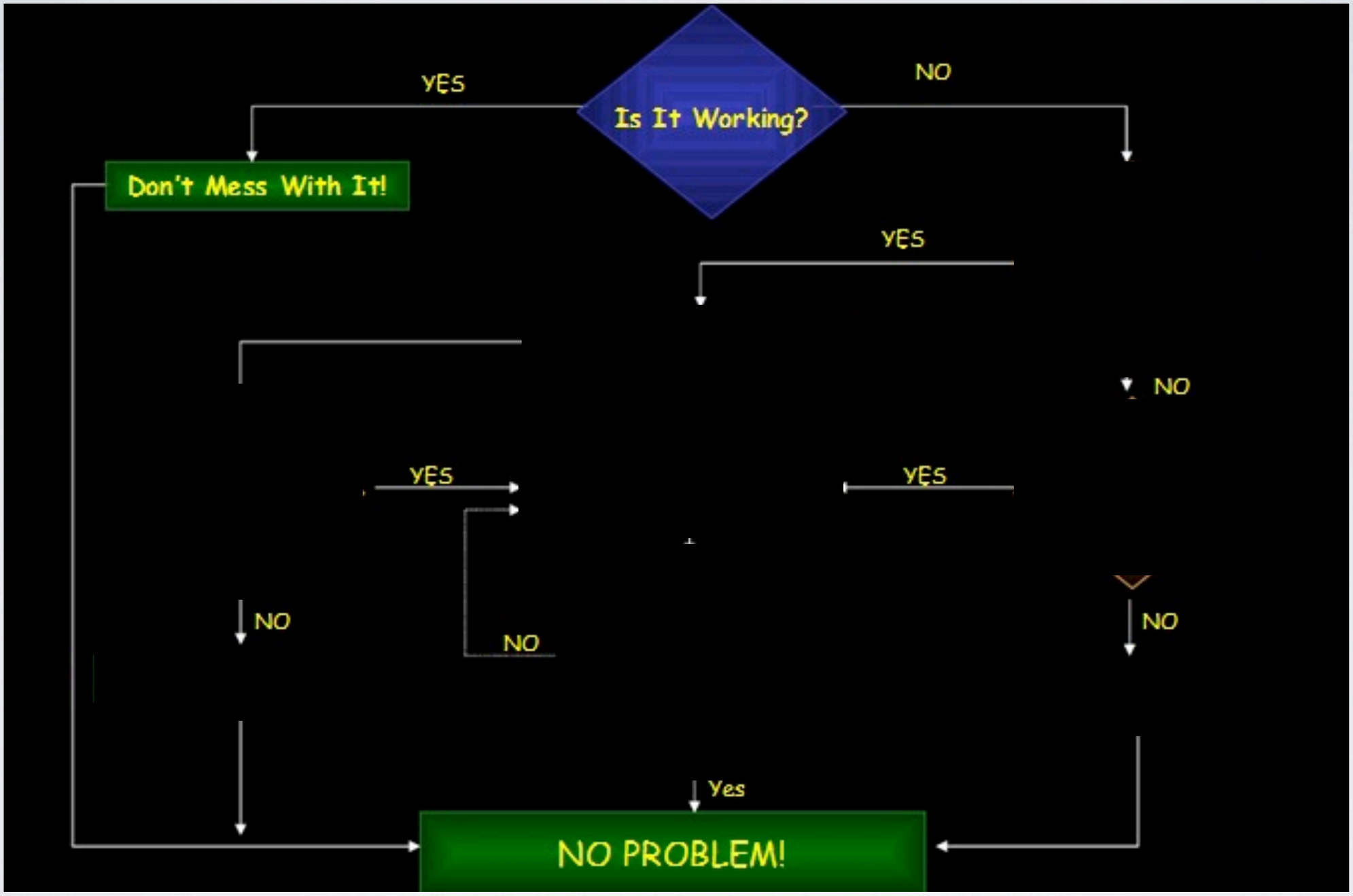

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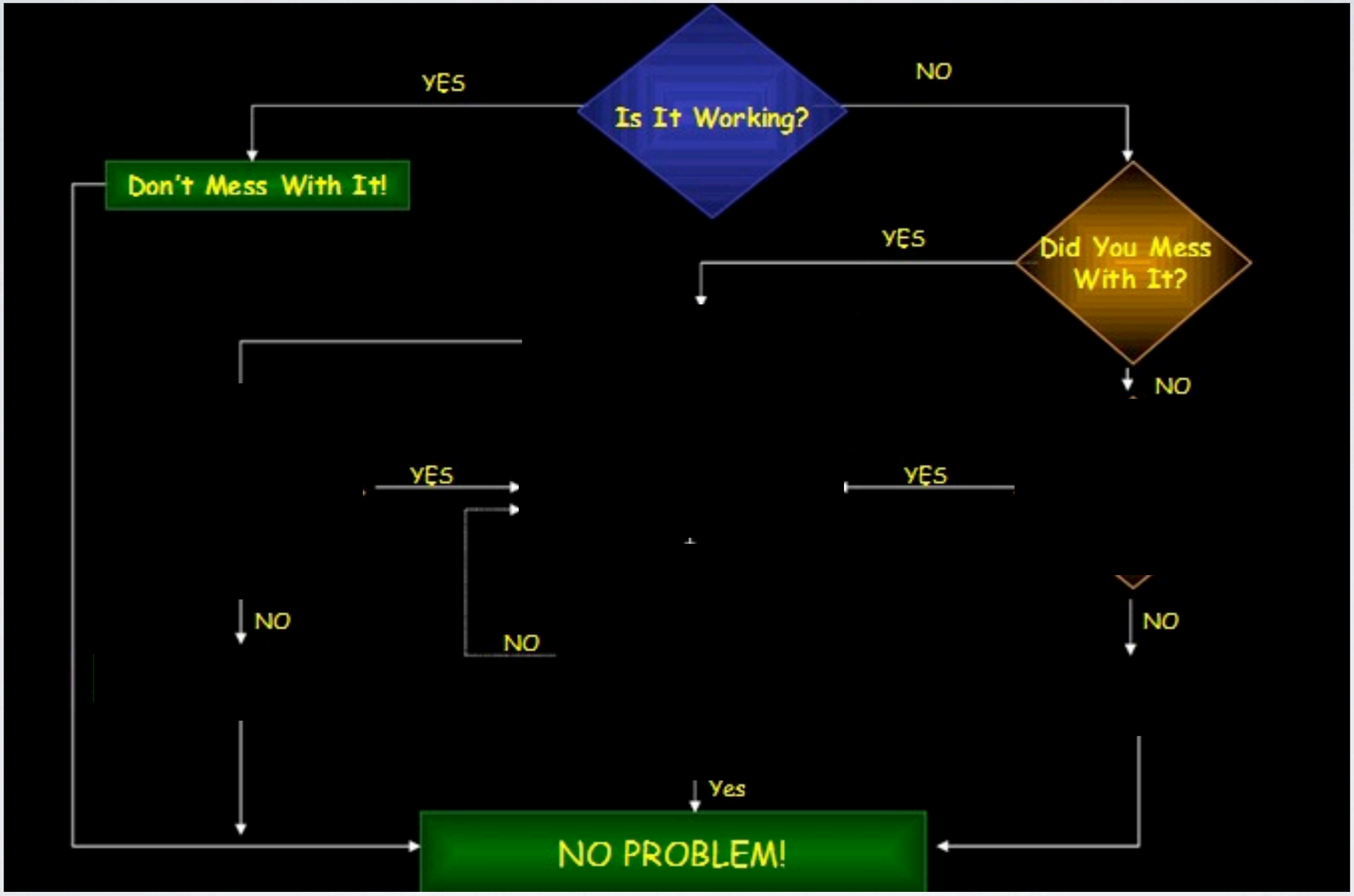

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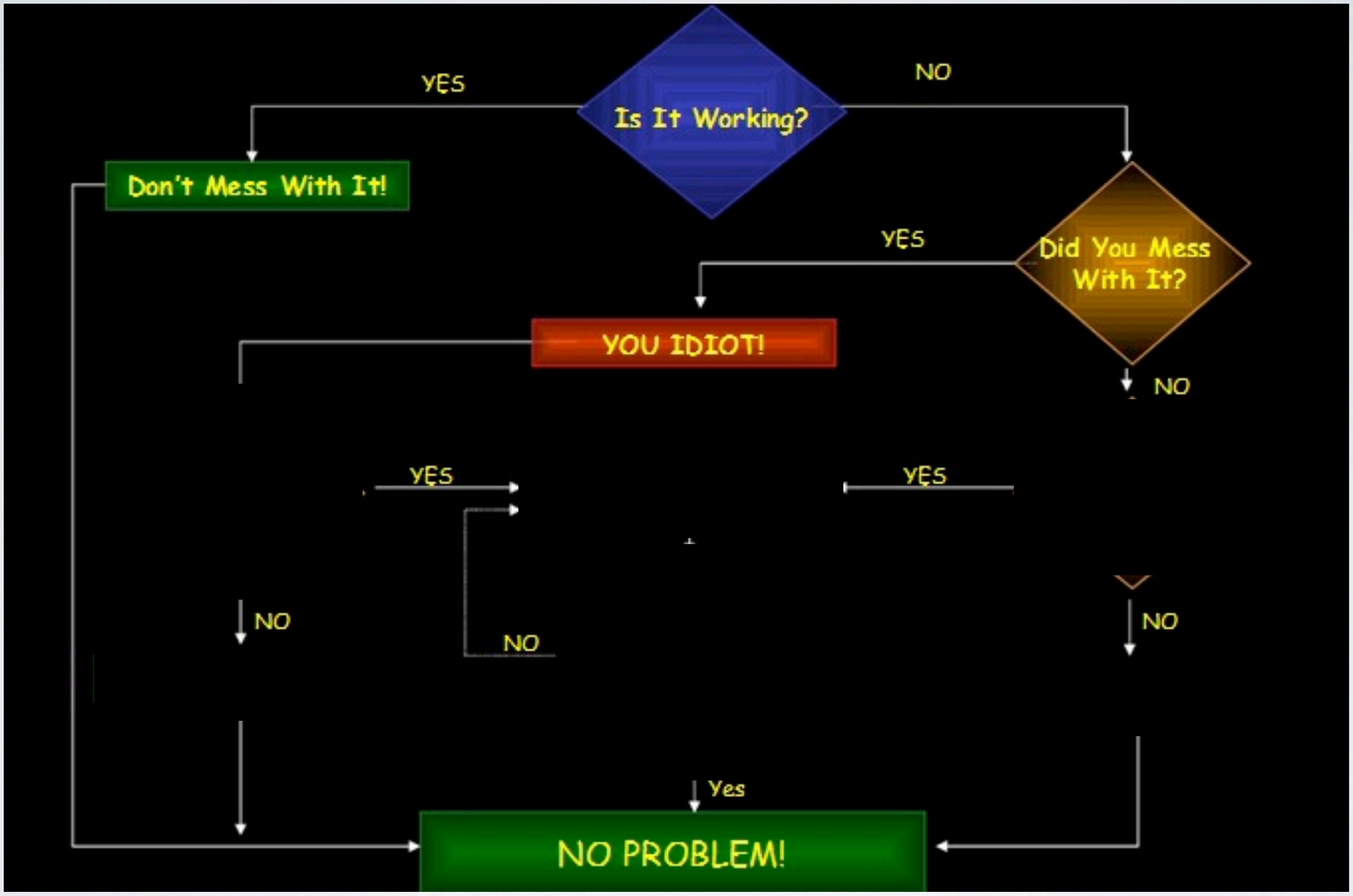

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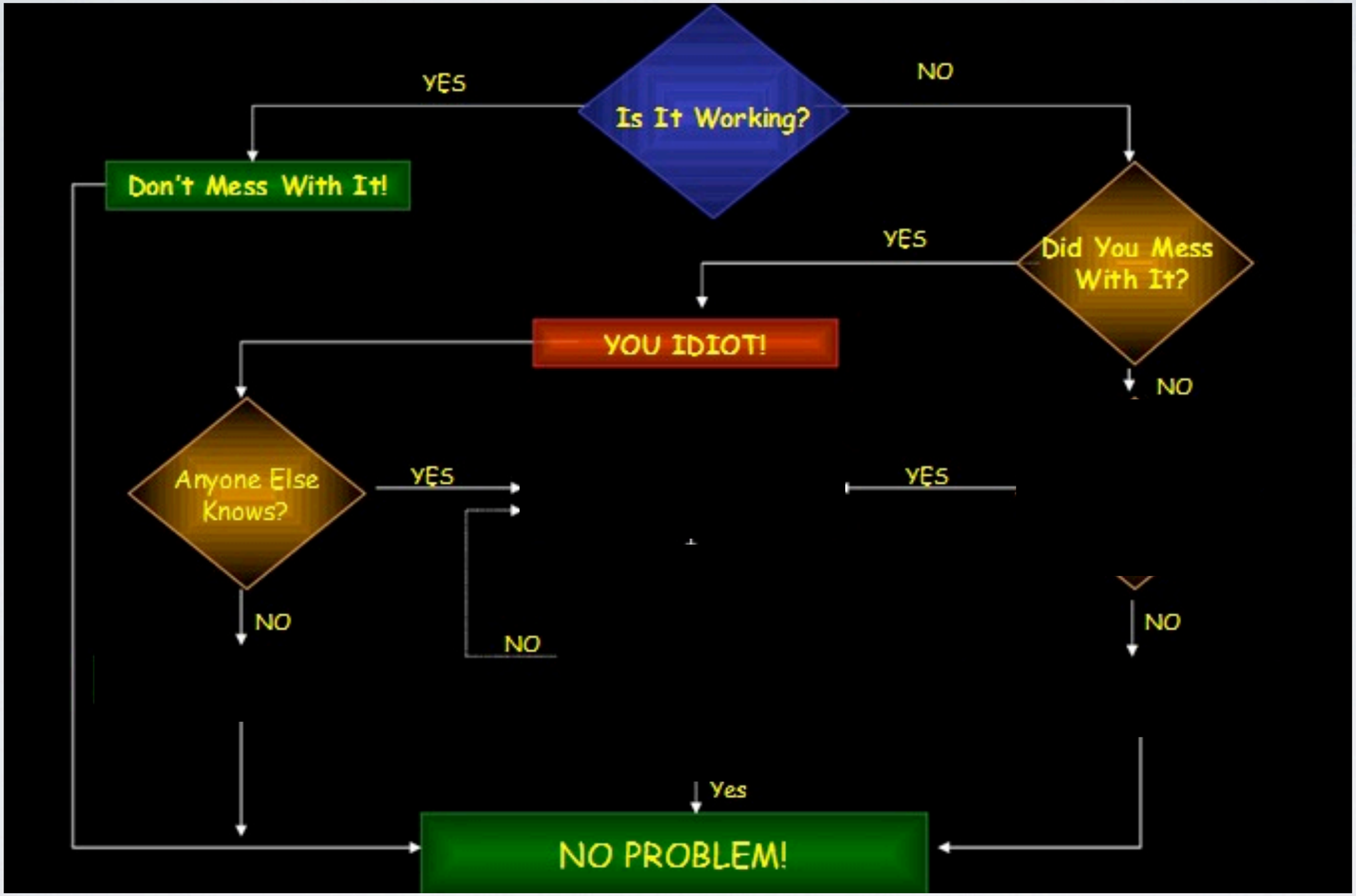

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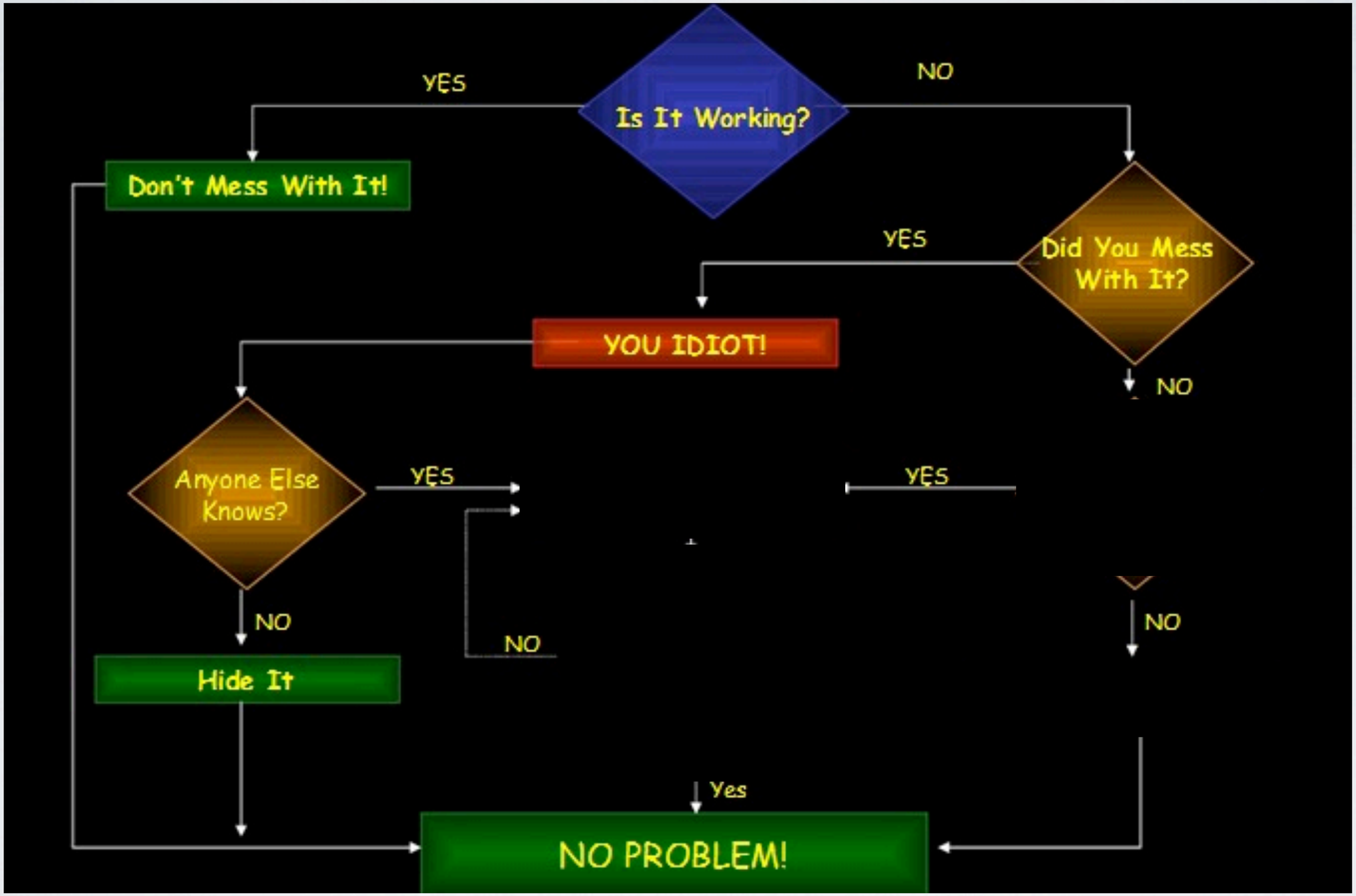

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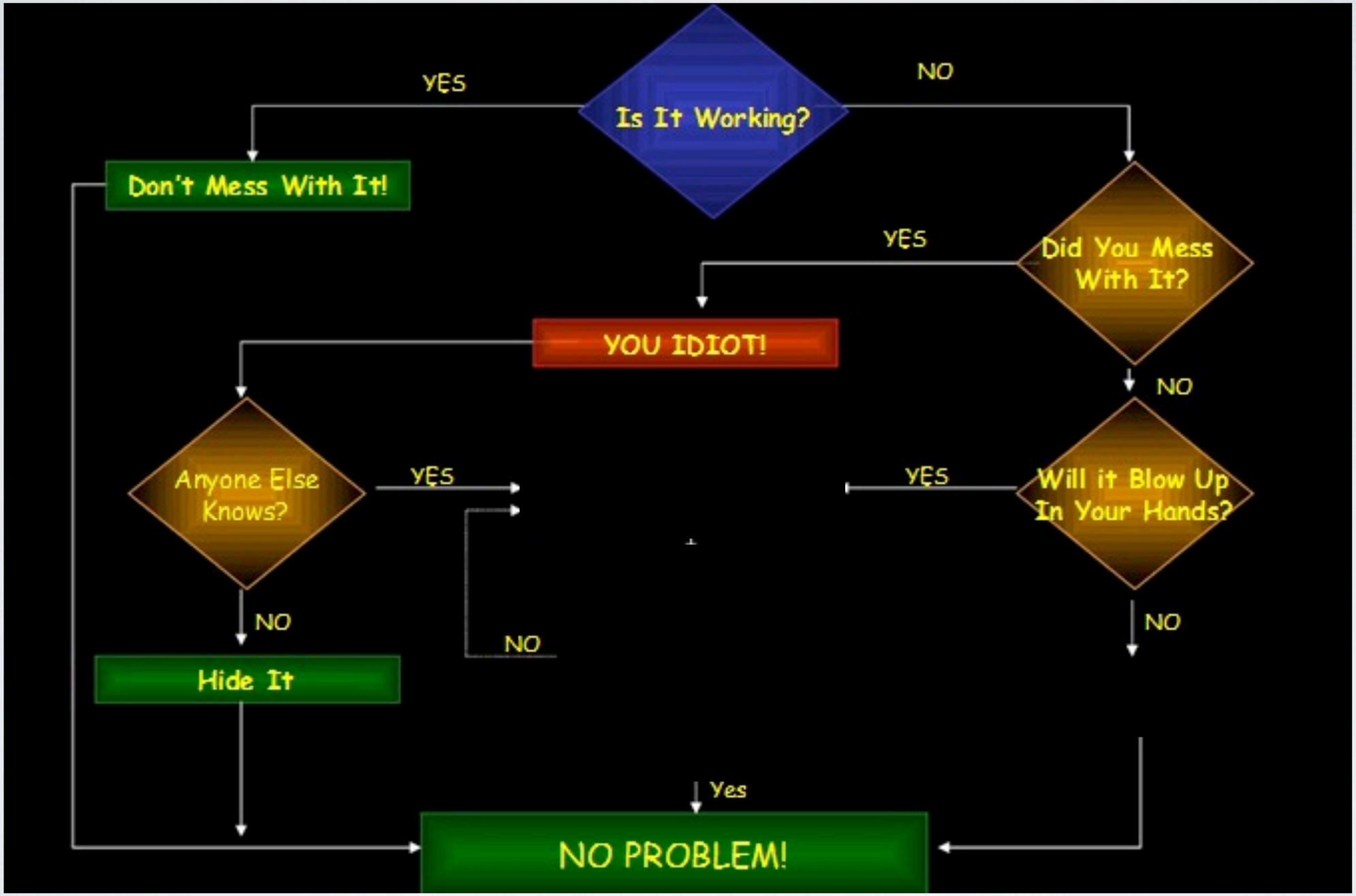

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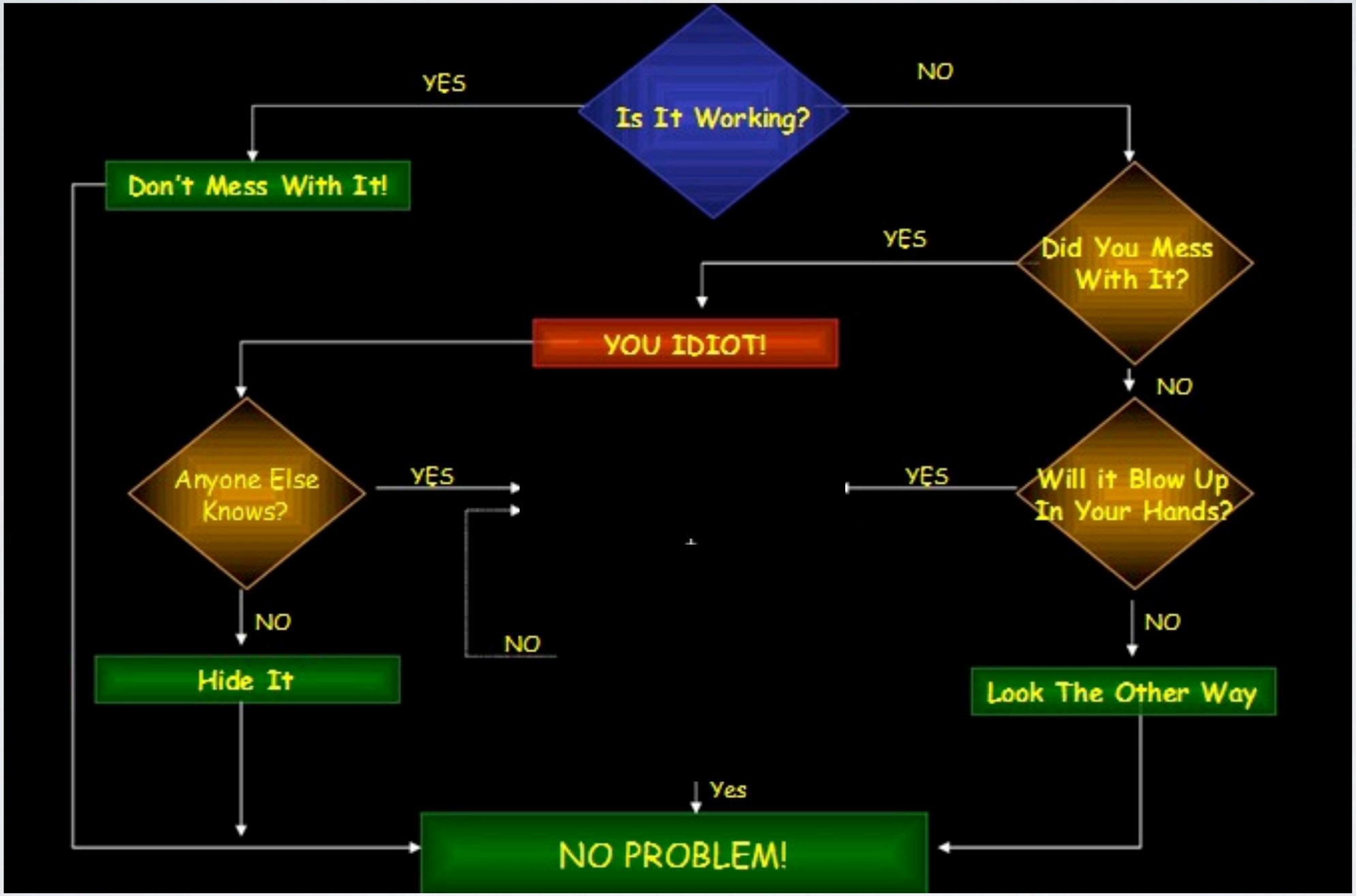

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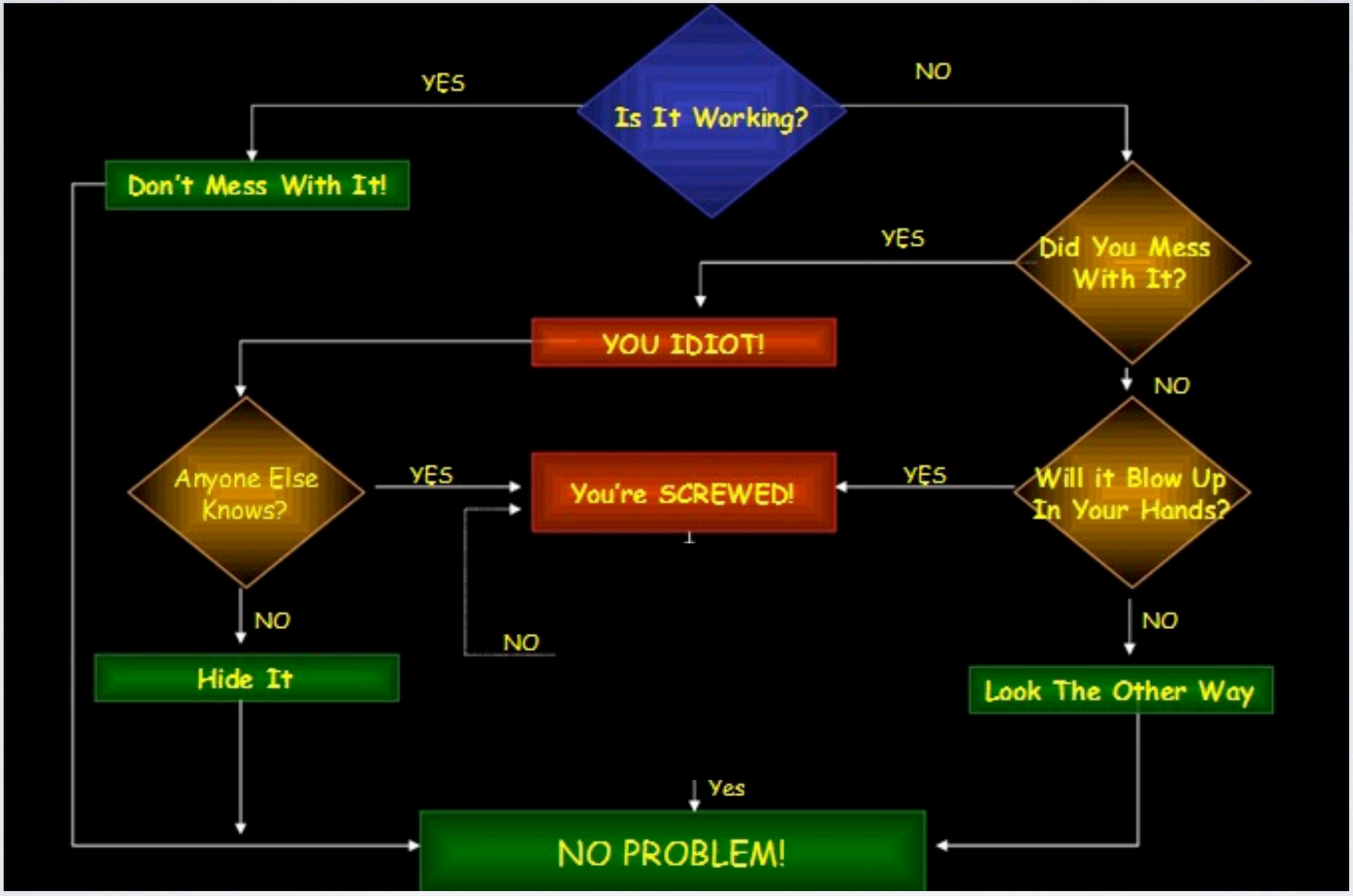

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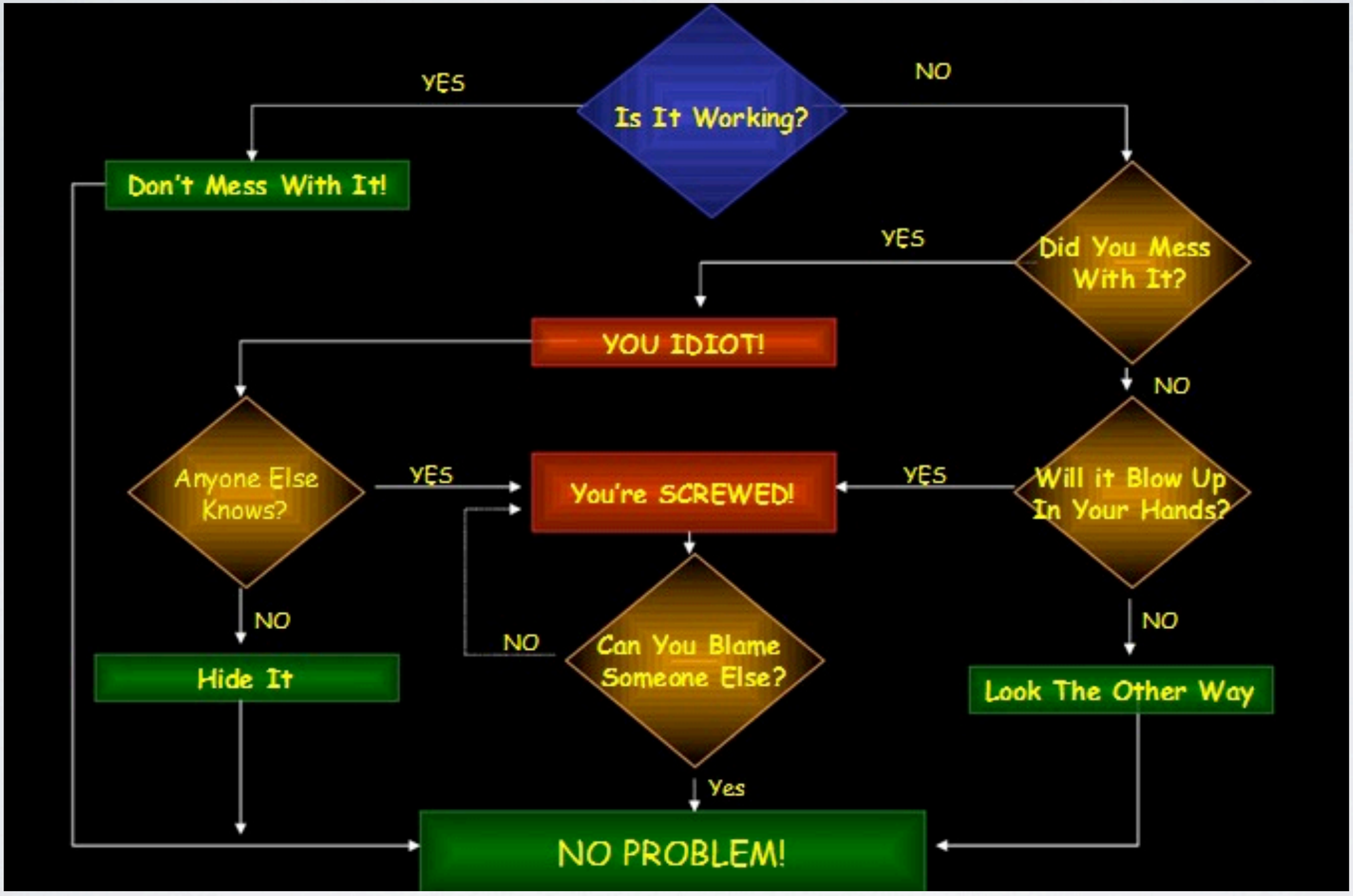

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Humidity loads

Dehumidification

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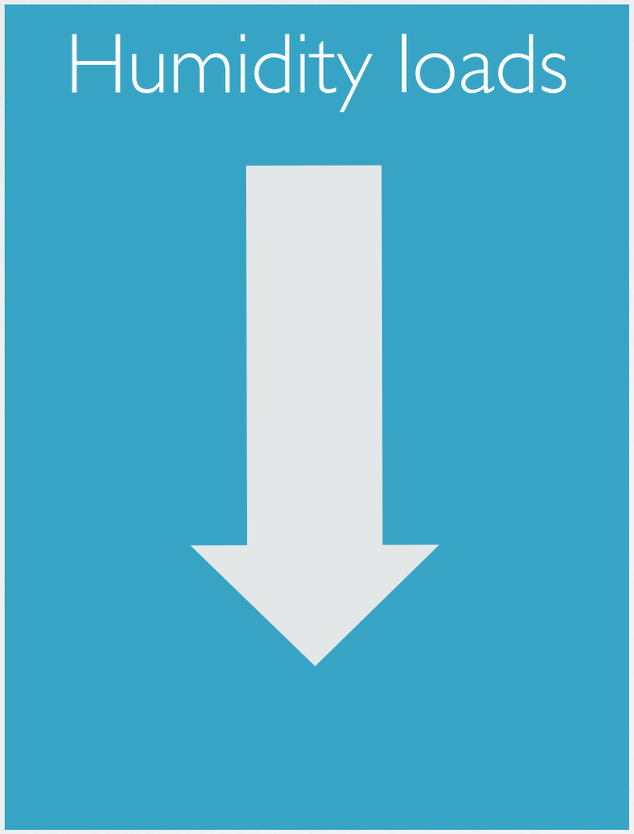

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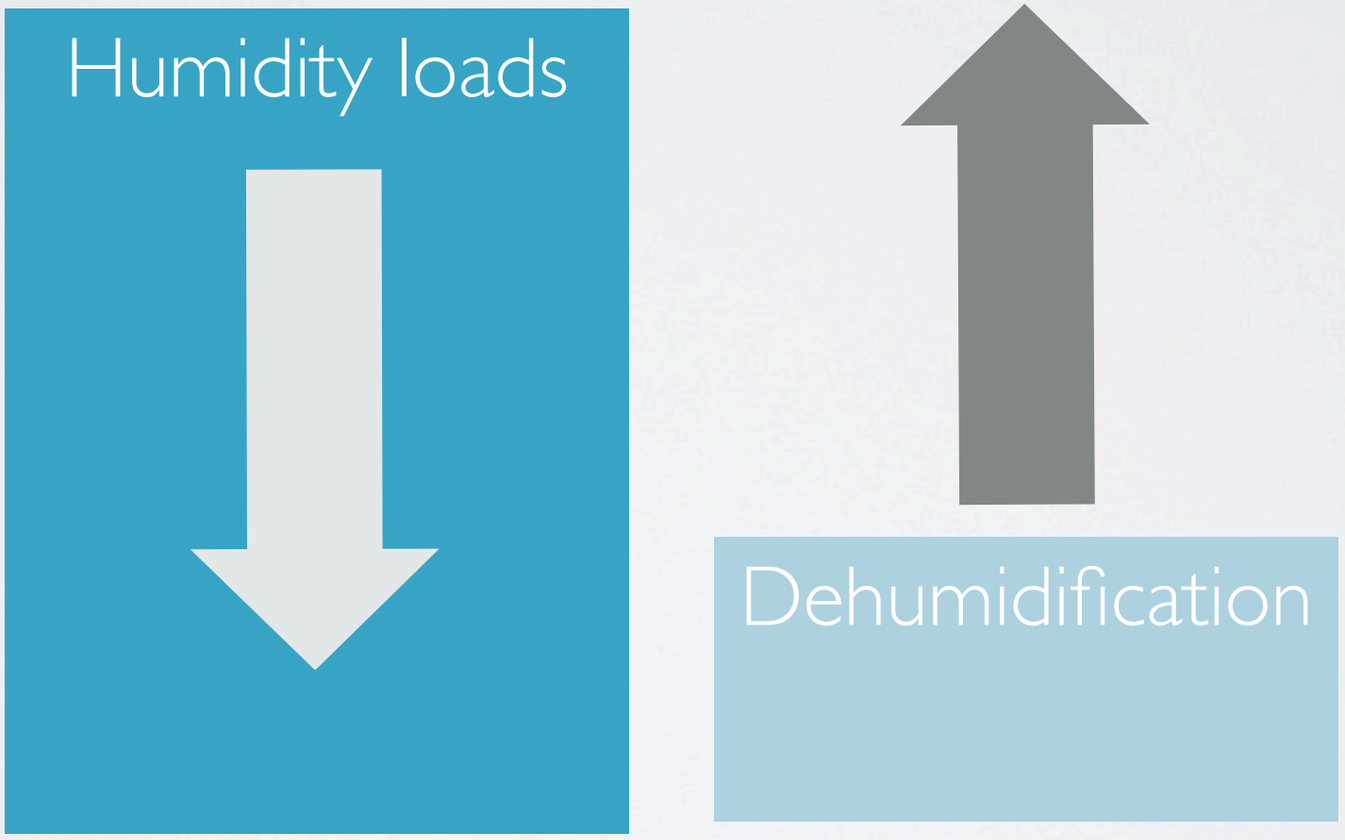


# Troubleshooting sequence

1. Listen and understand the problems

2. Look at drawings, then walk though and understand the BUILDING

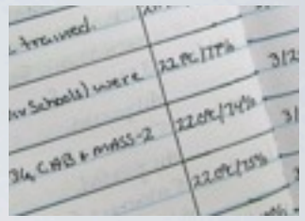
3. Look at drawings, then walk though and understand the HVAC SYSTEM

4. Measure the key variables
   a. The loads
   b. The dehumidification

5. Diagnose the problems... plan solutions

# Troubleshooting sequence





1. Listen and understand the problems

2. Look at drawings, then walk though and understand the BUILDING

3. Look at drawings, then walk though and understand the HVAC SYSTEM

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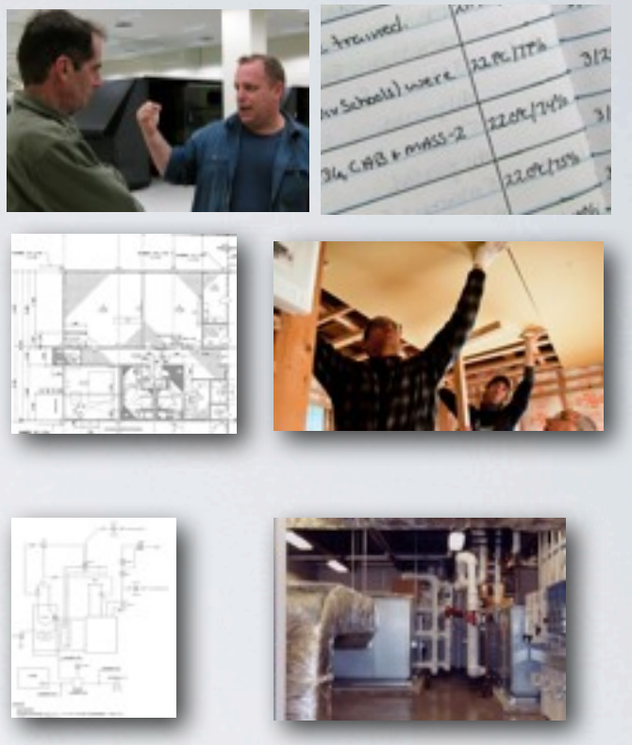

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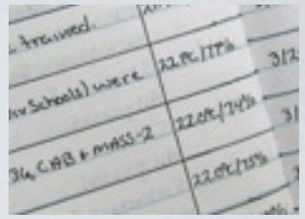





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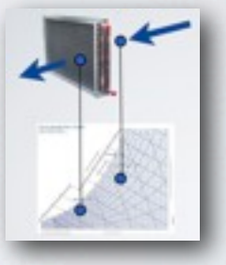

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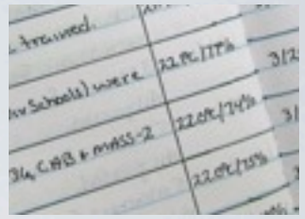

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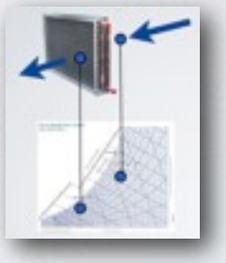

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2. Review the building drawings. Then walk through the building and around it, to understand the enclosure.
3. Review the HVAC drawings, equipment schedules and controls, then walk around, to understand the DH capacity.

# Then... start thinking about the problems



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# Next, MEASURE **loads**...
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- Humidity loads
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Humidity loads

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**How to measure?**

**Flow Hood**

# Measuring humidity loads - Exhaust air flow

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**How to measure?**

**Flow Hood**



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**How to measure?**

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How to measure?

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Exhaust air flow

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**Building air leakage**

Number of people

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How to measure?

**Blower door**

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How to measure?

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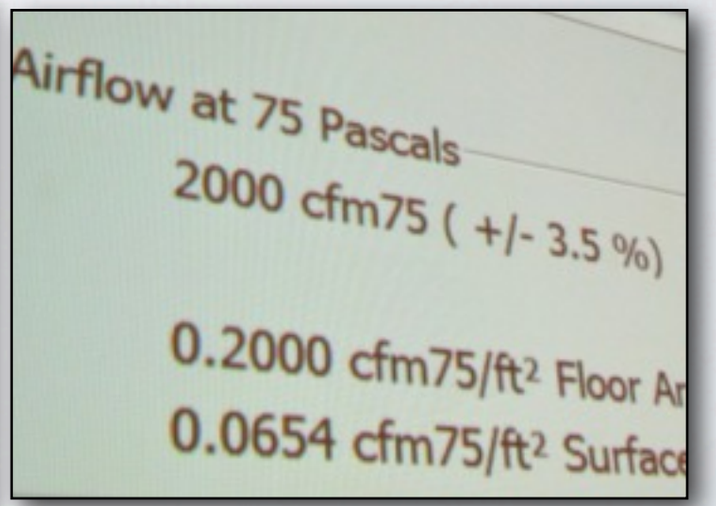

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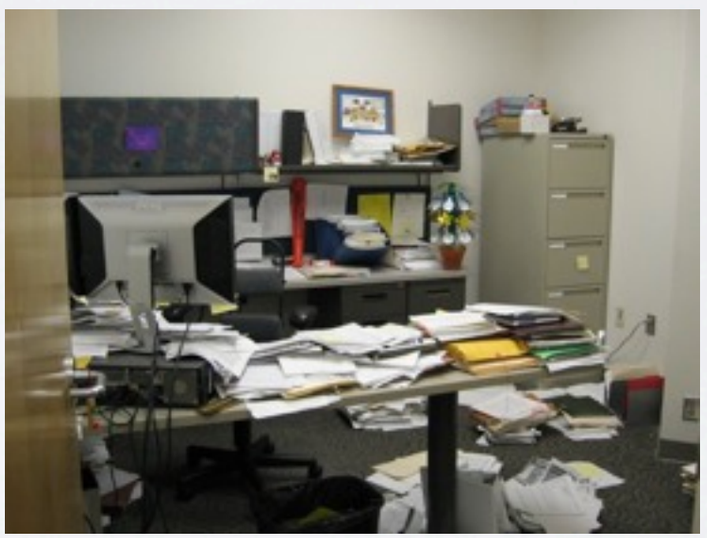





# Measuring humidity loads - Wet surfaces

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Dehumidification

Humidity removal

Dry air flow

Controls

# Measuring Dehumidification - Humidity removal

Dehumidification

Humidity removal

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# Measuring Dehumidification - Humidity removal

**First..**
**Find the**
**Dehumidifier!**

Dehumidification

Humidity removal

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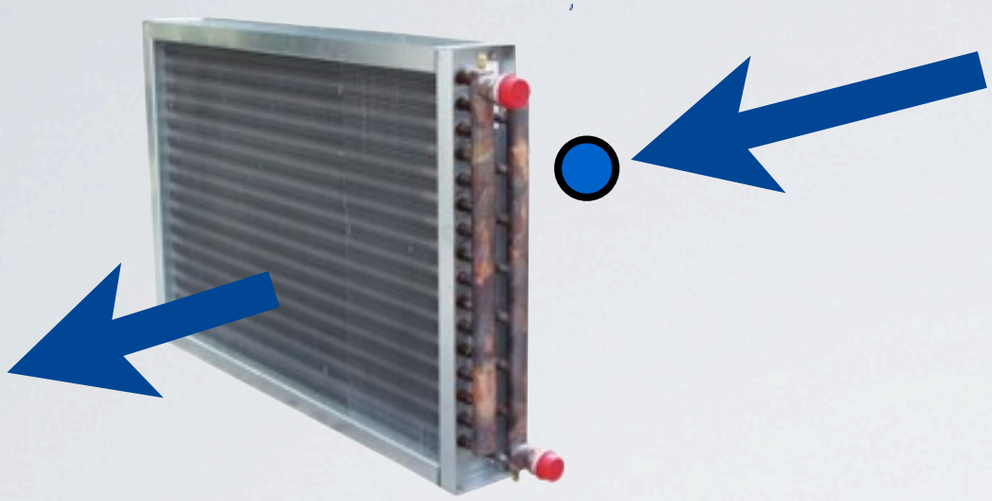

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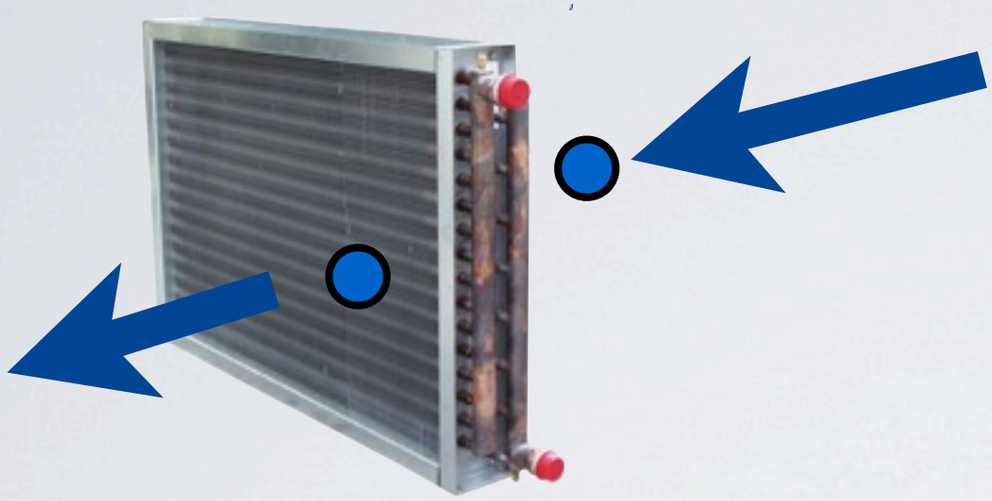

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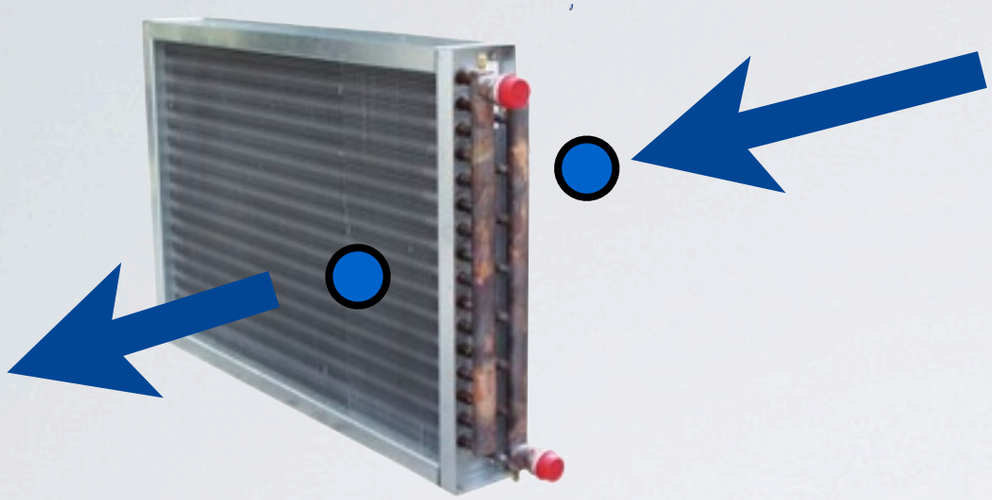

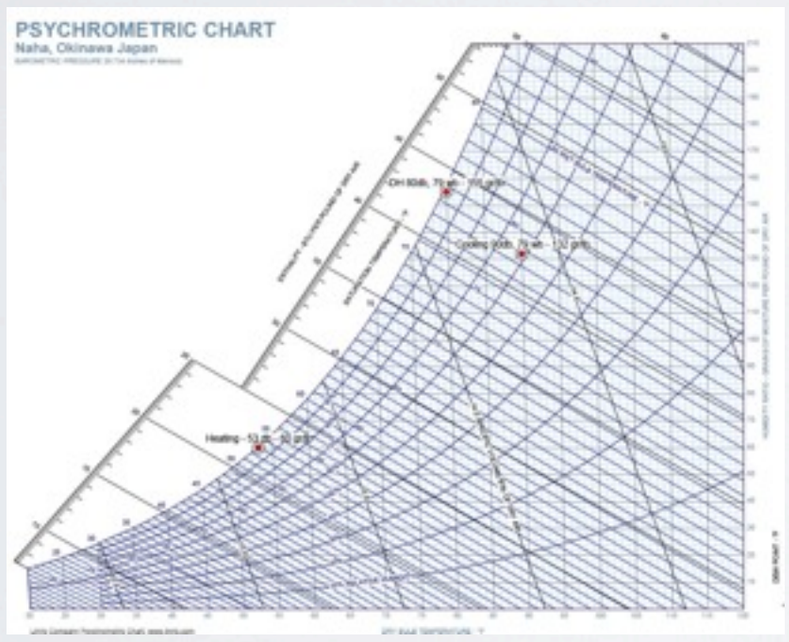


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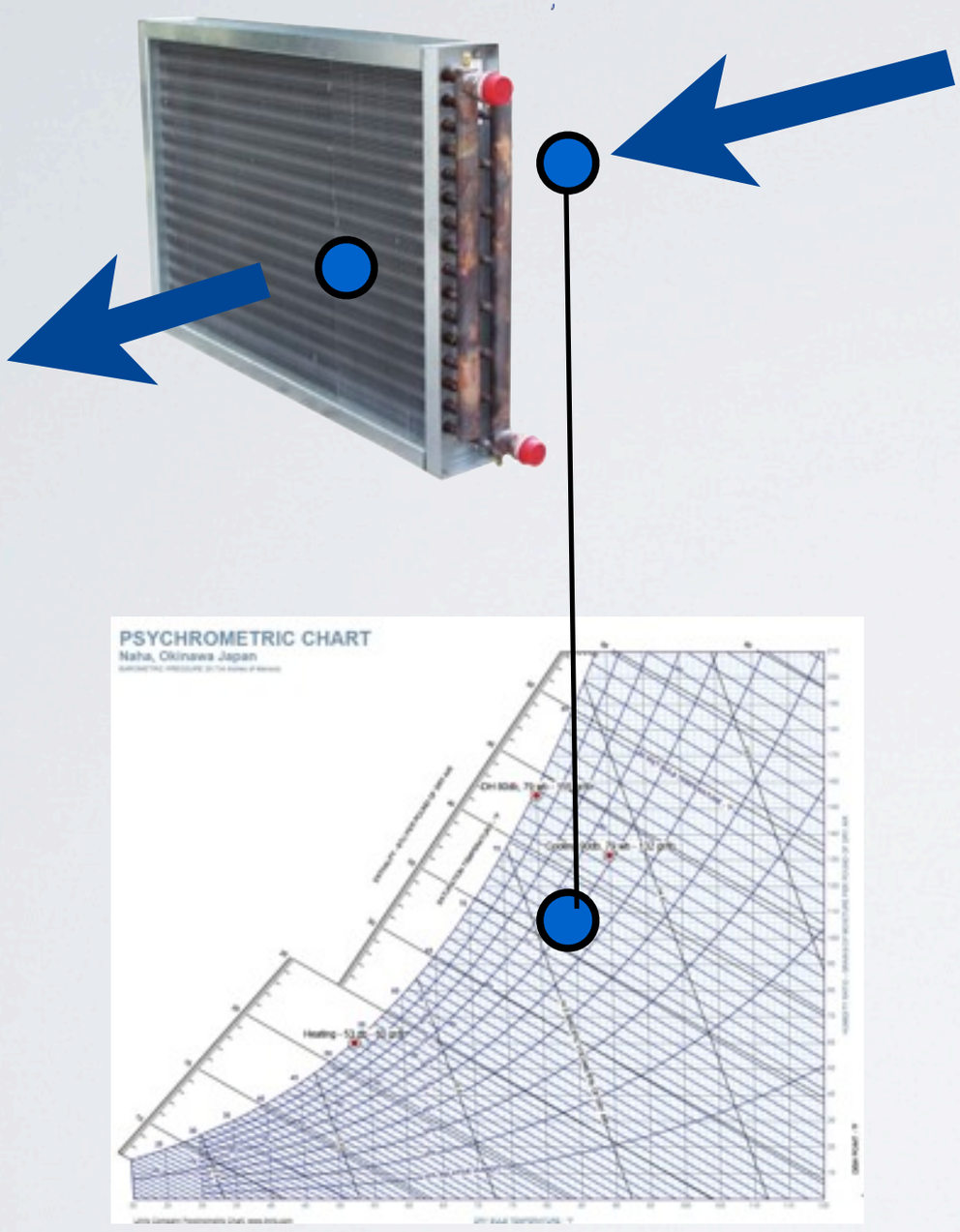


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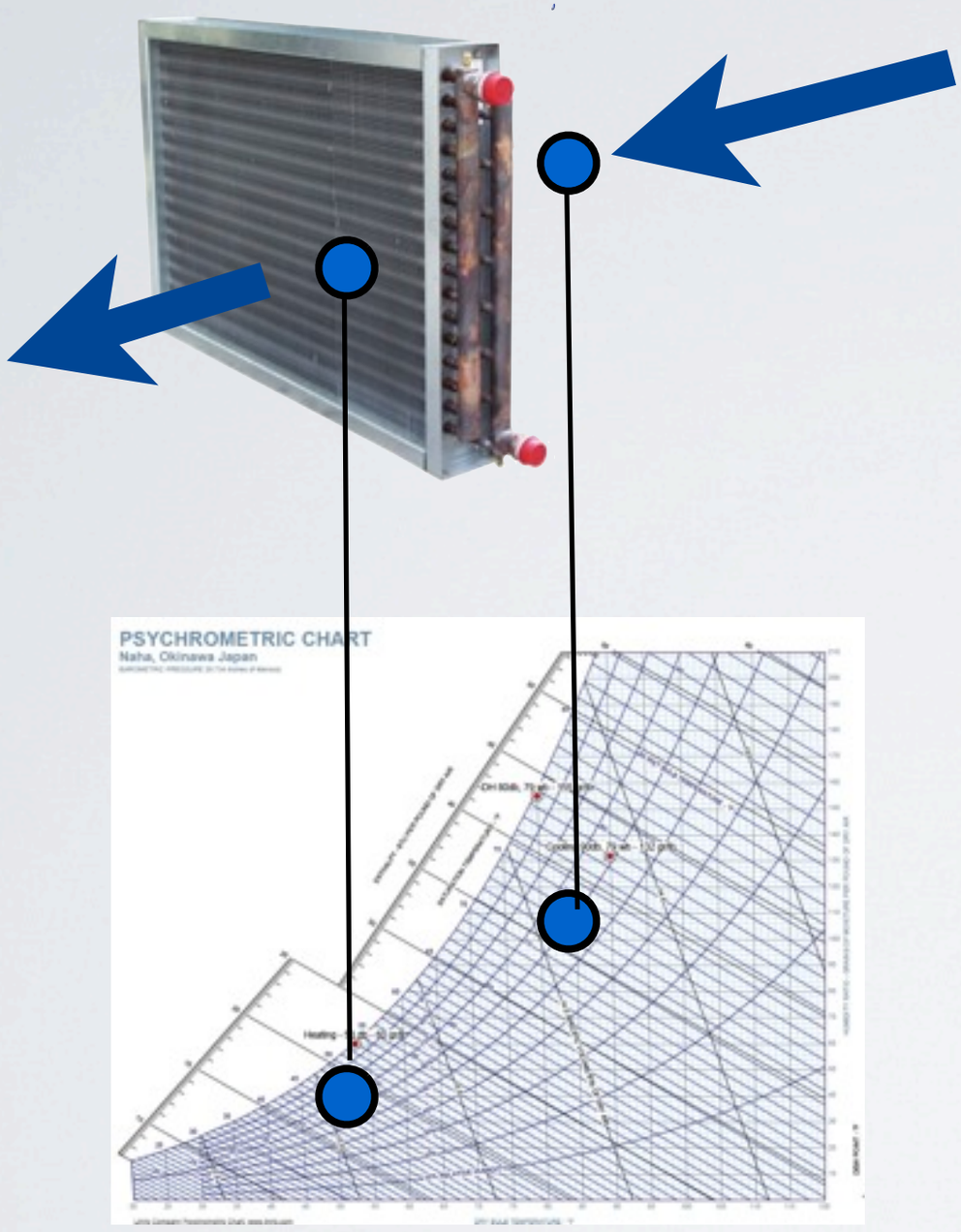


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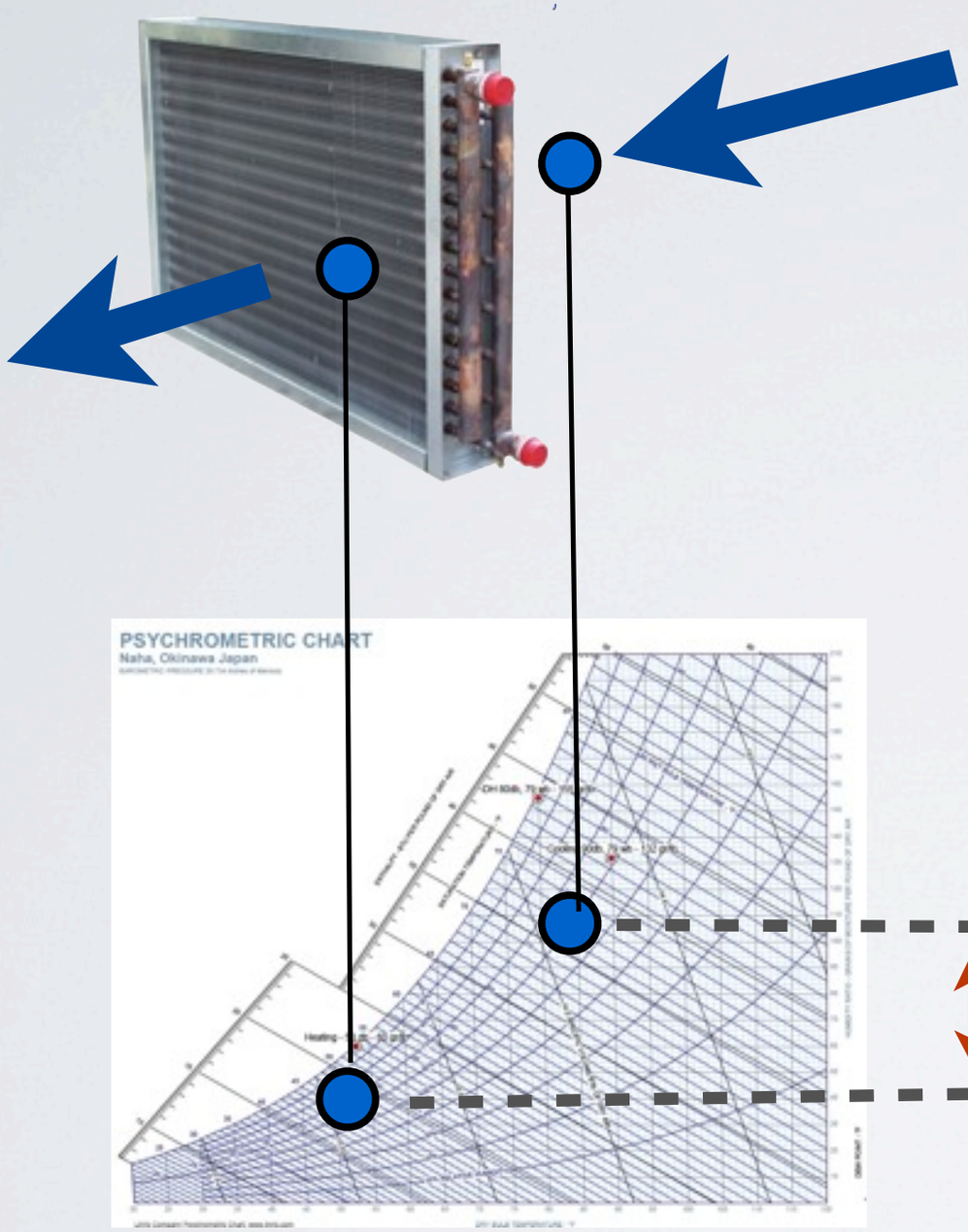


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Dehumidification

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**How to measure?**

**Flow Hood.... or Pitot Tube and Calculator**

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Dehumidification

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**How to measure?**

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Dehumidification

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How to measure?

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Dehumidification

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How to measure?

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Dehumidification

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How to measure?

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Dehumidification

Humidity removal

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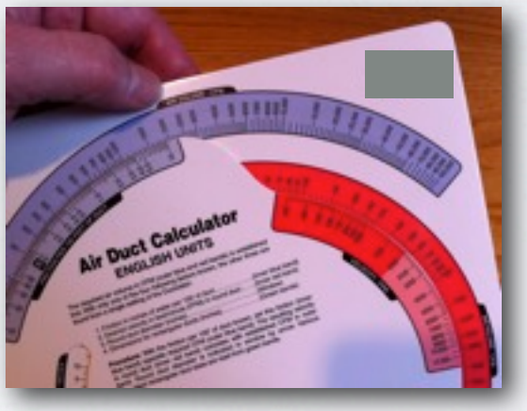


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Dehumidification

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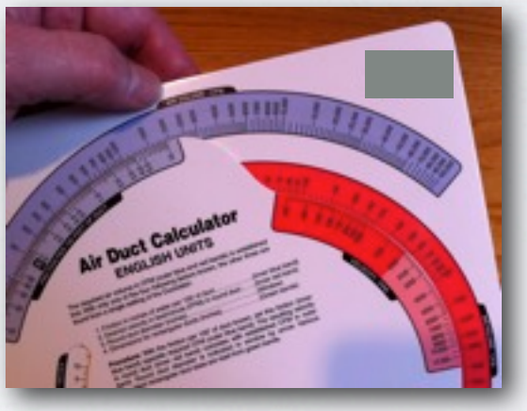





How to measure?

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# Measuring Dehumidification OVER TIME - Controls

Dehumidification

Humidity removal

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**Controls**

# Measuring Dehumidification OVER TIME - Controls

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Humidity removal

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Controls

**Do they really work?**

**Review diagrams, place dataloggers**

**..then compare to the real world**

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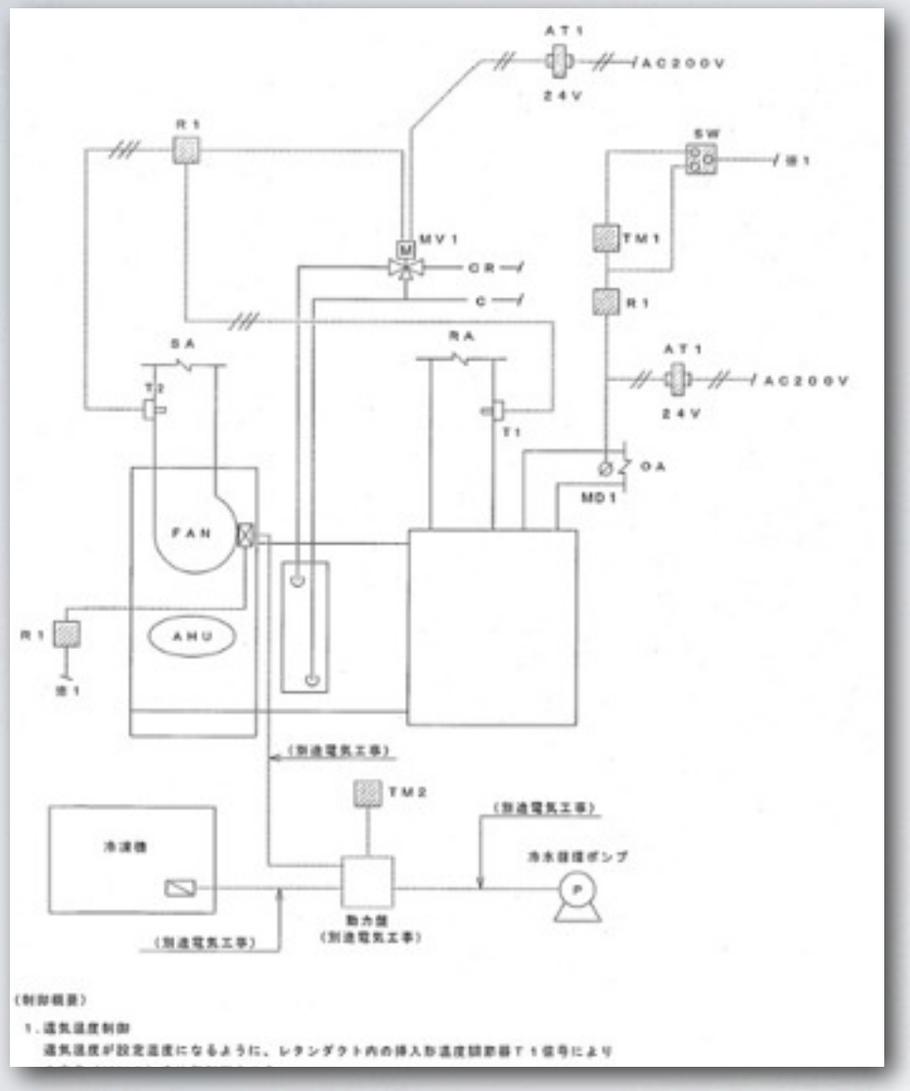


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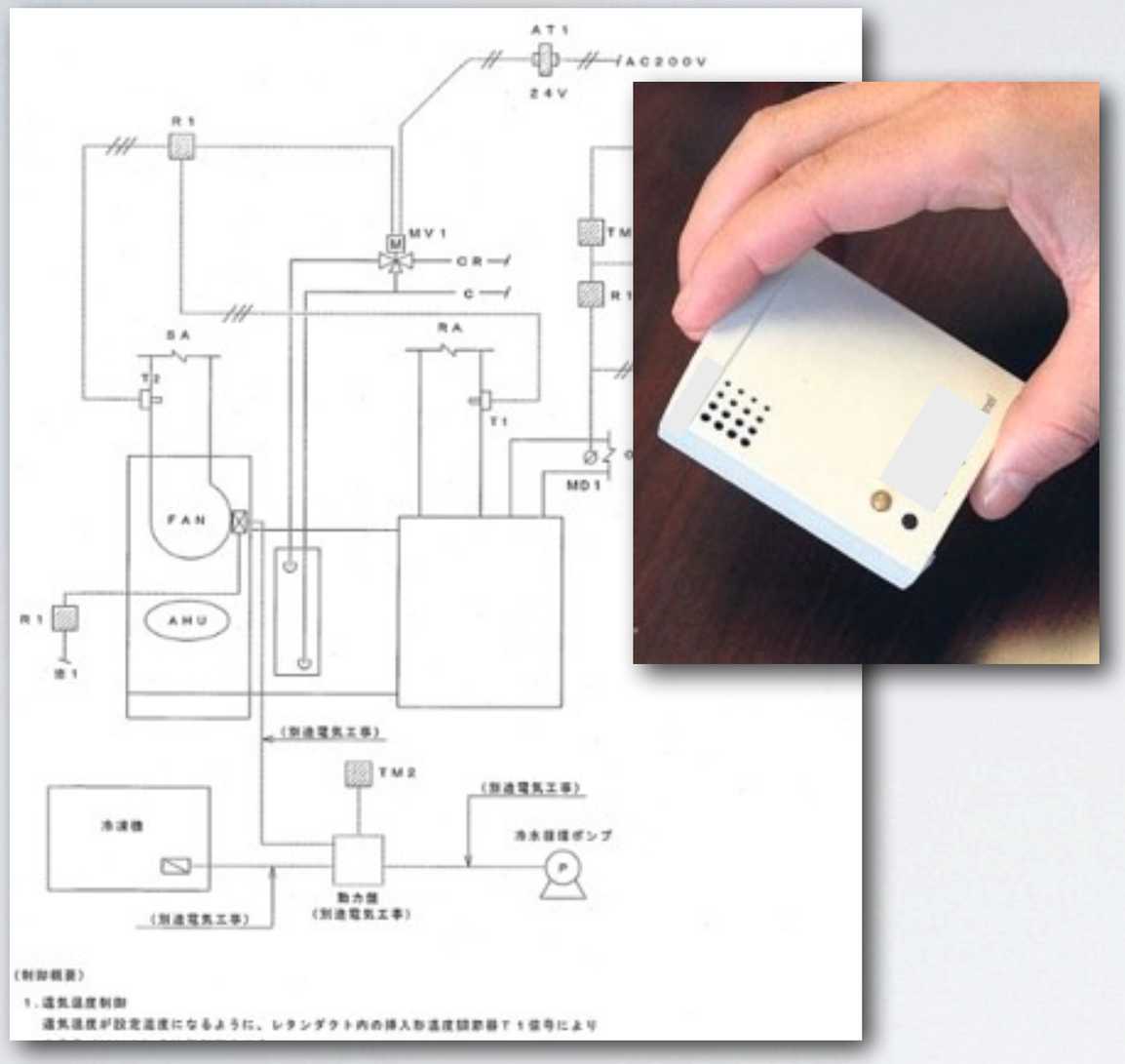




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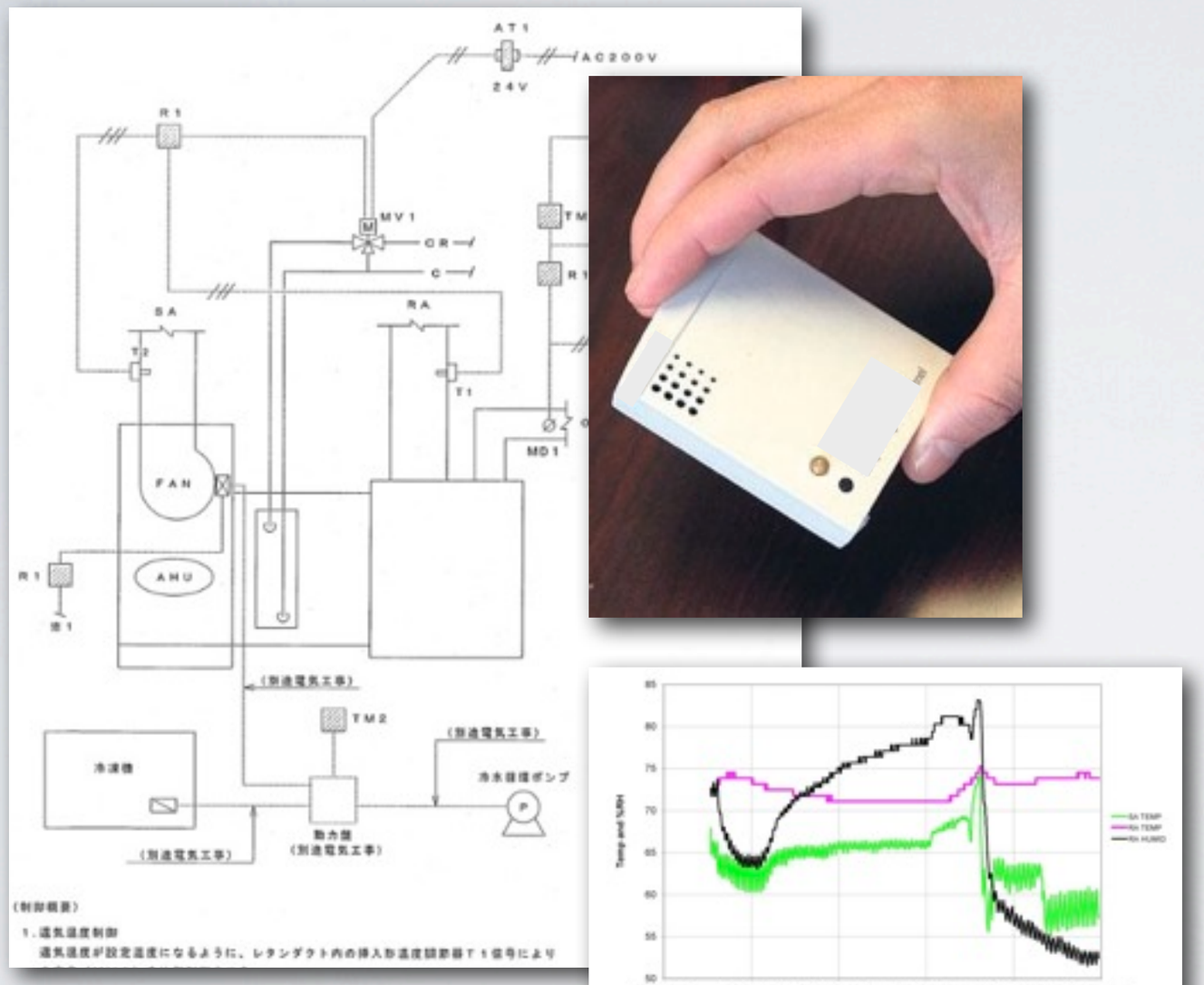







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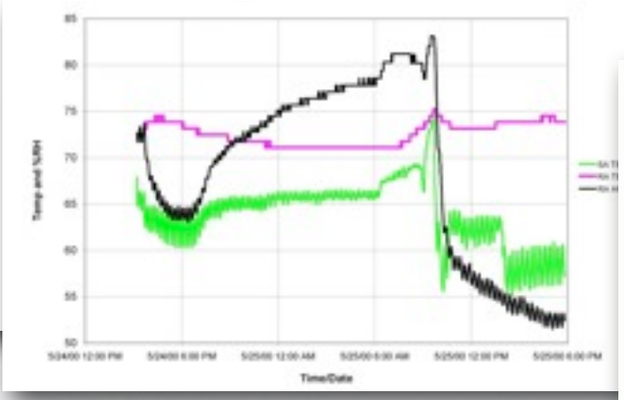
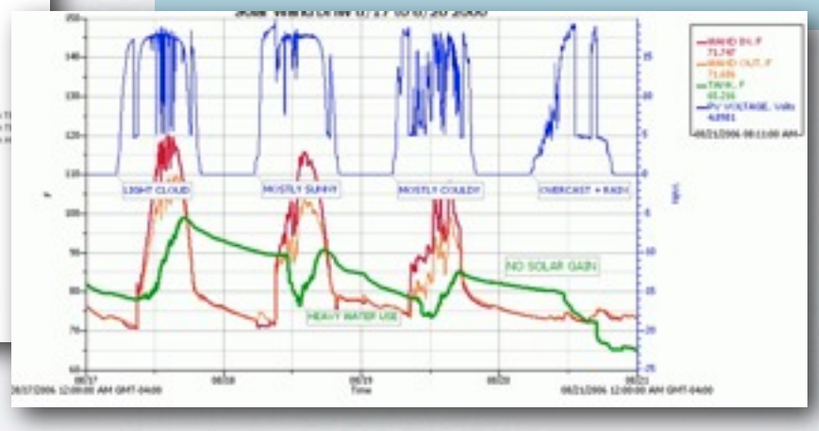
# Measuring Dehumidification OVER TIME - Controls






Dehumidification

Humidity removal

Dry air flow

**Controls**

## Do they really work?

## Review diagrams, place dataloggers ..then compare to the real world

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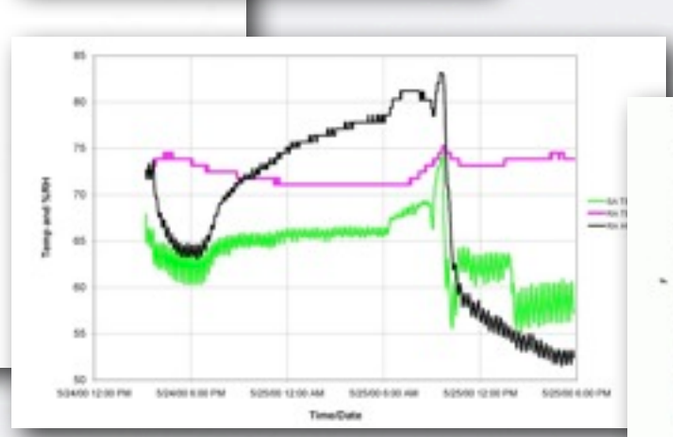


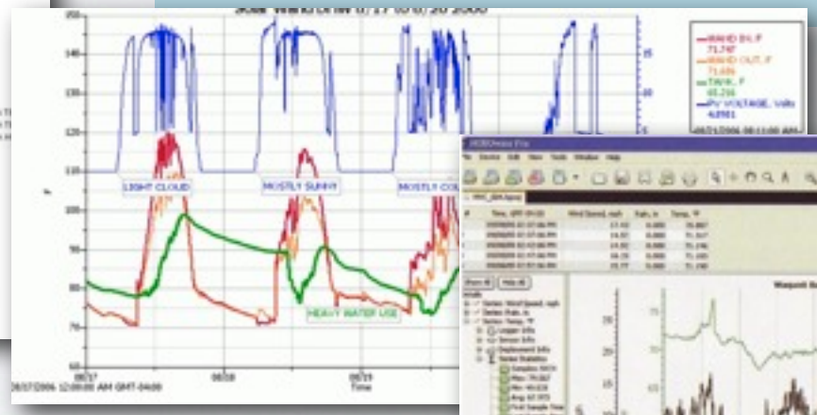


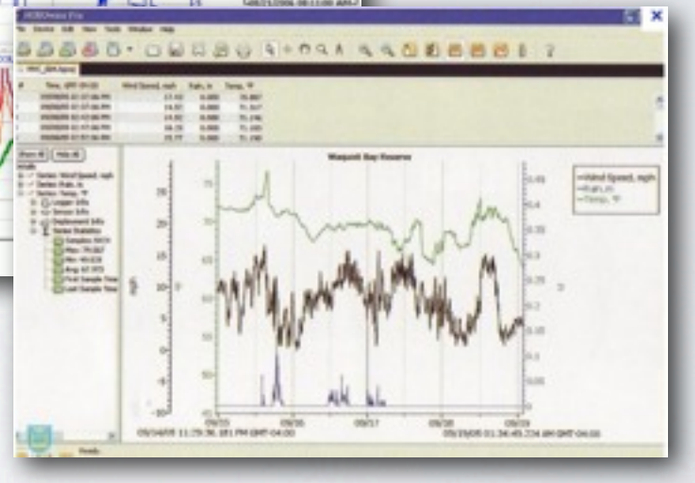

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# Logical sequence - Summary

1. Listen and understand the problems
2. Look at drawings, then walk though and understand the building
3. Look at drawings, then walk though and understand the HVAC system
4. Measure the key variables
   a. The loads
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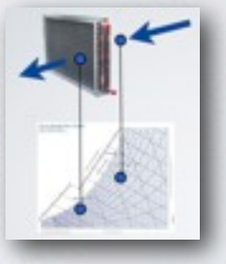

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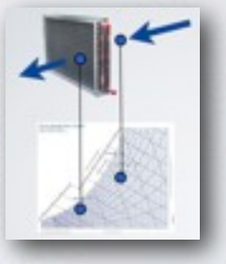

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# Community Clinic - Malaysia



# Problems at the clinic

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- Bad publicity forced closure and mold remediation in 2008
- Engineering firm had contract to remediate mold and re-adjust HVAC yet again. Wanted to get to the root of the ongoing problems and solve them... permanently.

# Air infiltration + humidity load

**Average Dew Point**

| Year | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73.4°F | 71.6°F | 71.6°F | 73.4°F | 73.4°F | 73.4°F | 73.4°F | 73.4°F | 71.6°F | 73.4°F | 73.4°F | 73.4°F | 71.6°F |



# Air infiltration + humidity load

55˚F dew point

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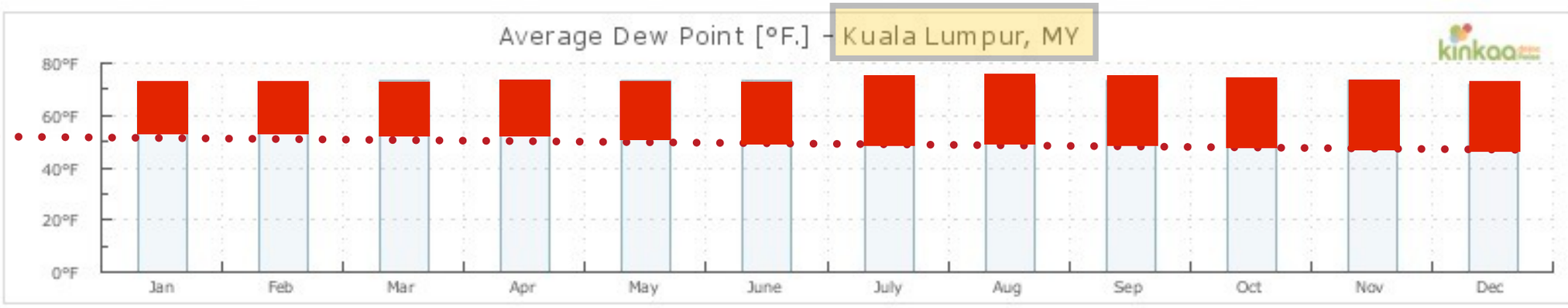

# Limited Hours of HVAC Operation



# Building floor plans



# Indoor dew point = 12.0˚C (54˚F) - Excellent!



# South-facing lobby, 1st floor - No mold



# South-facing lobby, 1st floor - No mold



# Examination rooms - Big problems with mold



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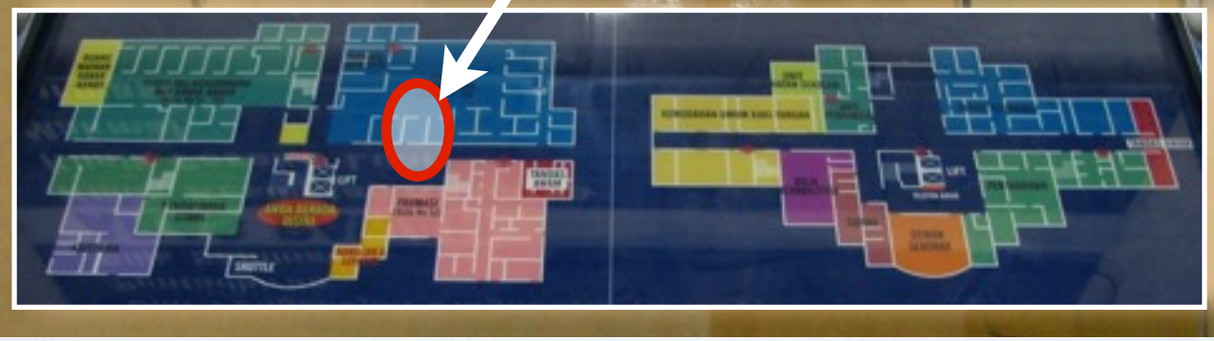

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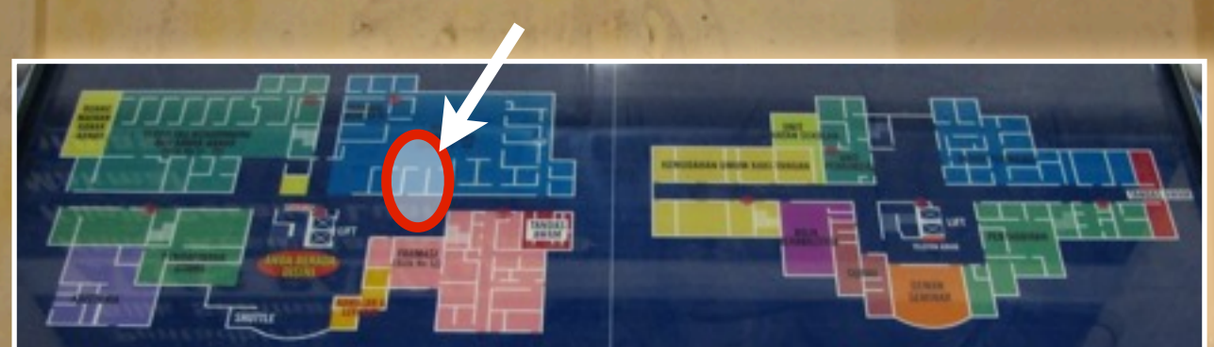

# Looking inwards... from the west wall



# Looking inwards... from the west wall



# 2nd floor - Looking outwards,  toward west wall



# 2nd floor - Looking outwards,  toward west wall



# 1st floor - East wing corridor



# 1st floor - East wing corridor



# Water-soaked insulation collapsed the ceiling



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# DAYLIGHT above the 1st floor ceiling....??!!



# DAYLIGHT above the 1st floor ceiling....??!!



# South elevation



# Note the gutter dimensions...



# Roof-wall connection



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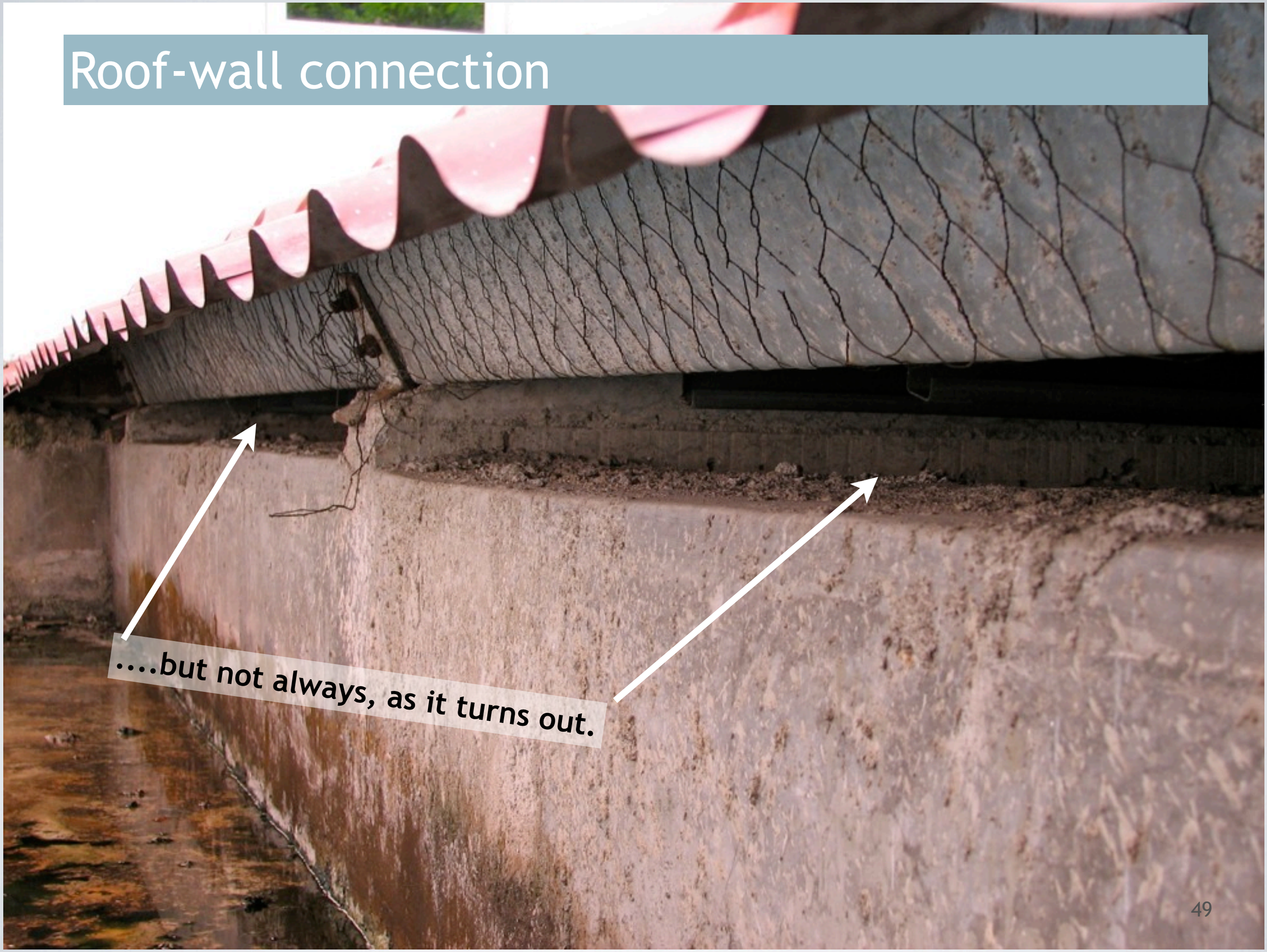

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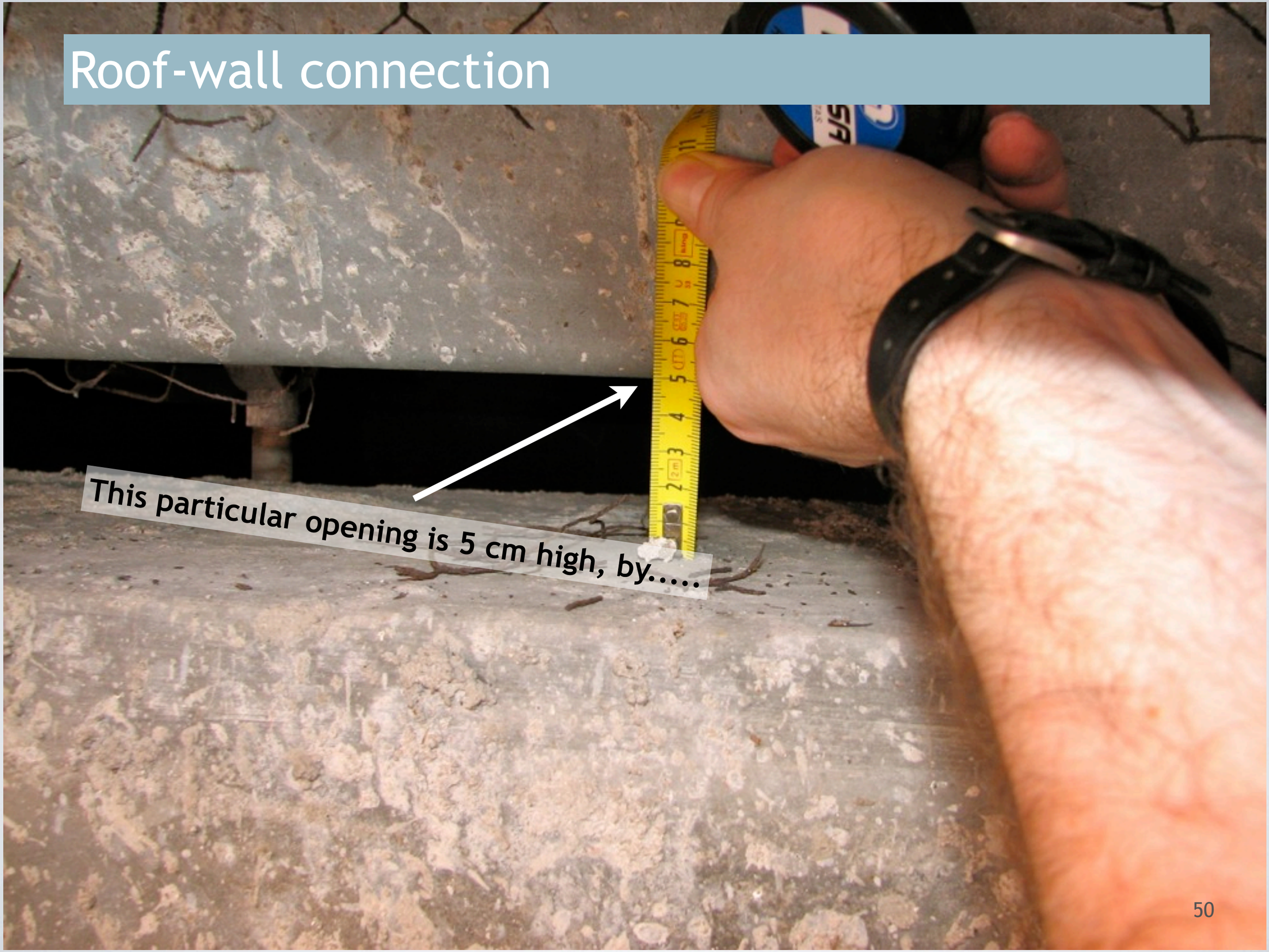

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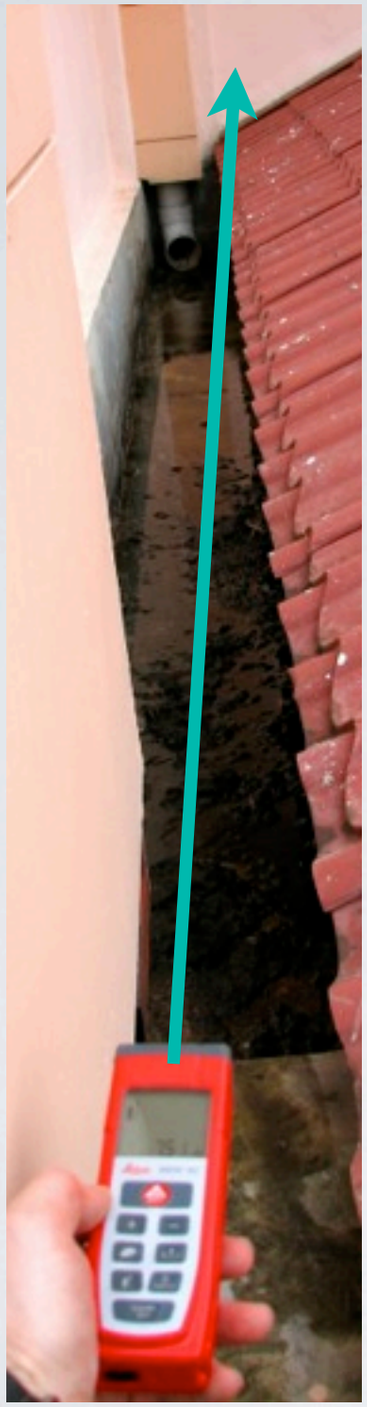



**by... 7.5 meters long (15 ft.)**

**So this particular gap measures 2.5 ft2 open area**

# Roof-wall connection



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# Roof-wall connection



# Installers don’t always pay attention to sealing up holes they make...



# Installers don’t always pay attention to sealing up holes they make...



# Excellent mechanical room - Entire 3rd floor



# Ventilation air enters through mechanical room



# ... but duct chases are not all sealed, so outdoor air falls into the building after entering though the mechanical room



# 54°F indoor dew point when systems are operating....



... rises to 66°F dew point only 20 minutes after systems turn off..



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... which means the rh AT THE SURFACE is over 95%

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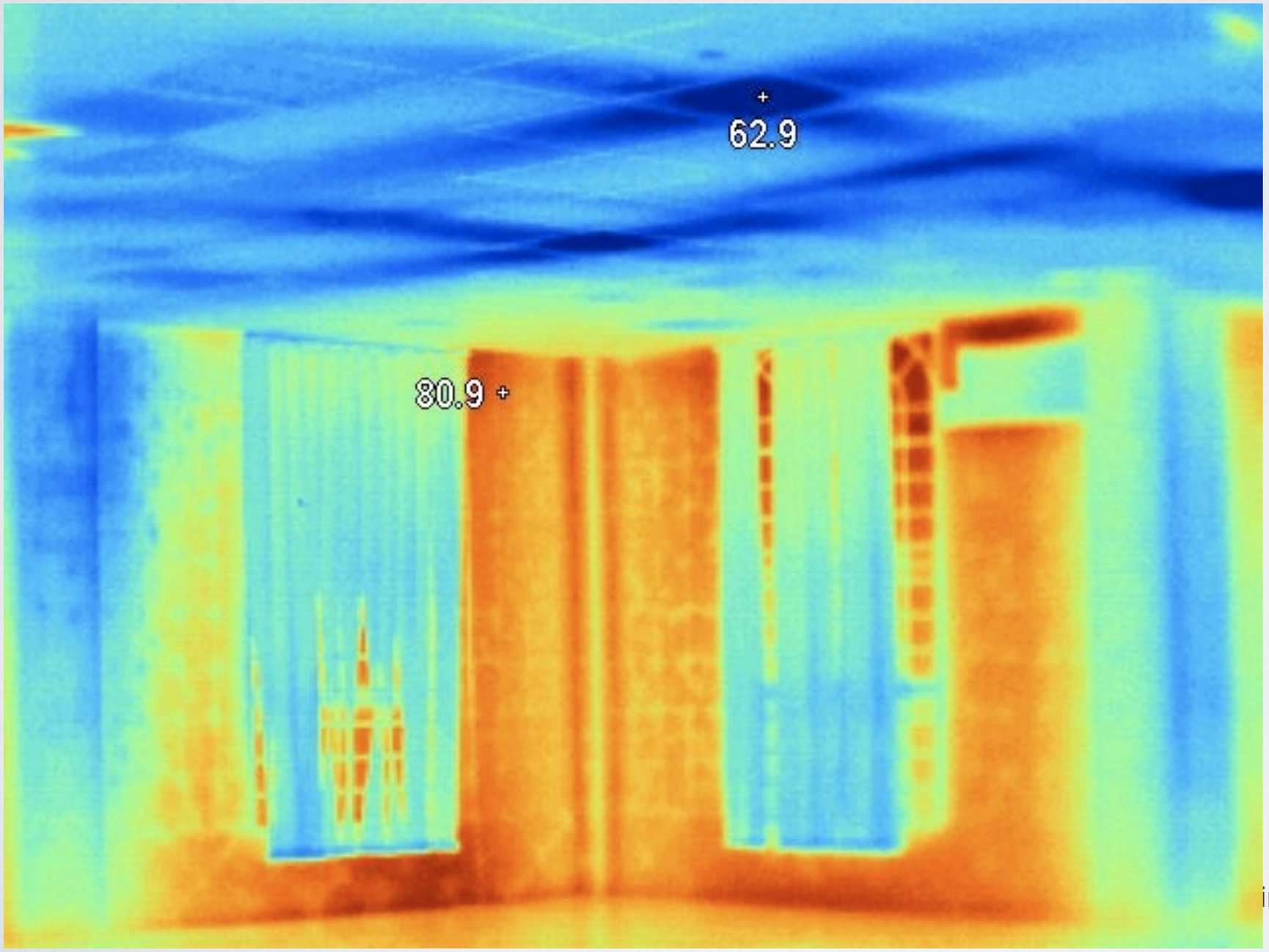
The mold grows because high dew point outdoor air easily falls into the building through the wide gaps and holes..

... while the AC system overchills the building under the mistaken assumption that more cooling = humidity control and mold avoidance

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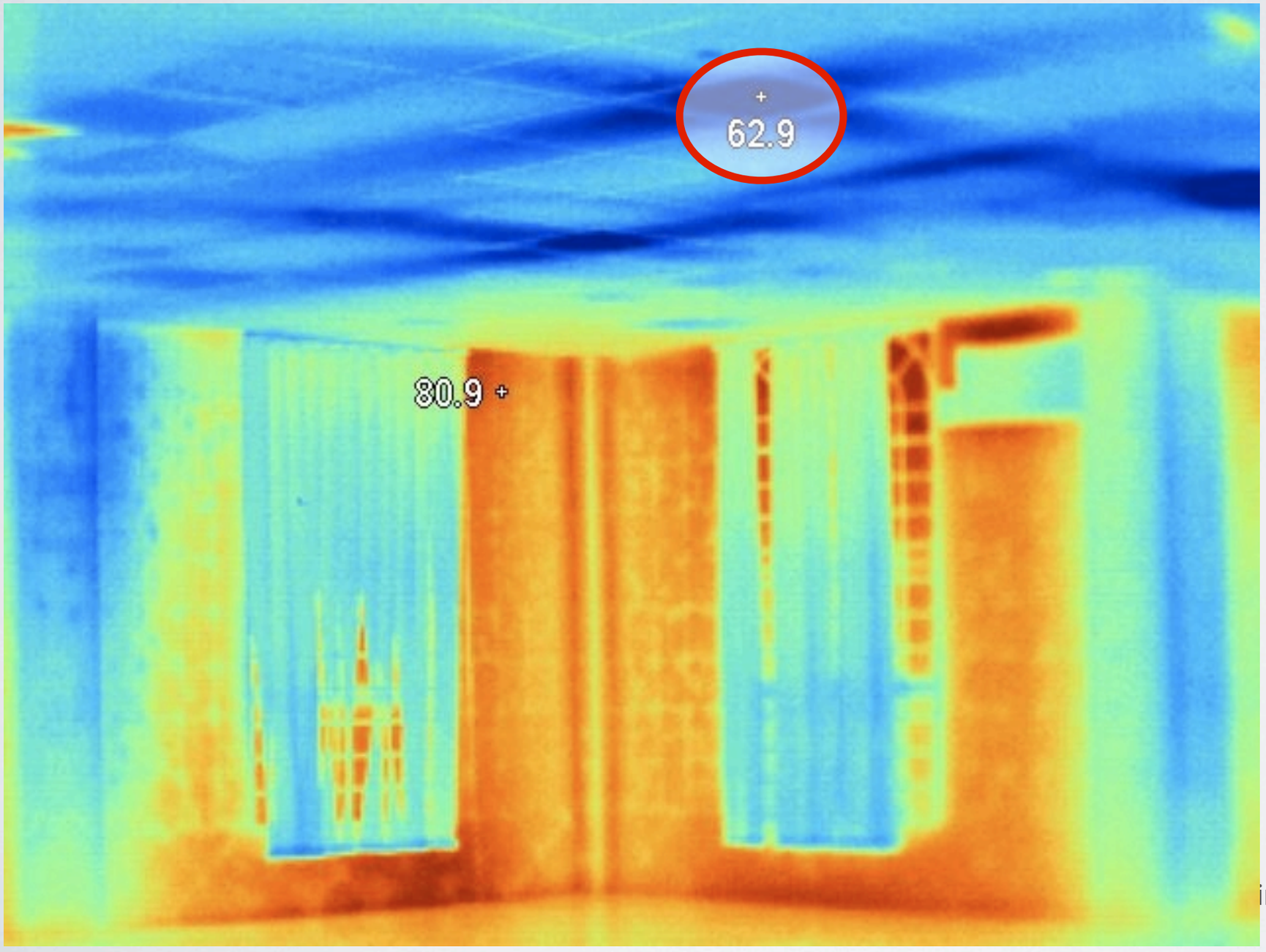


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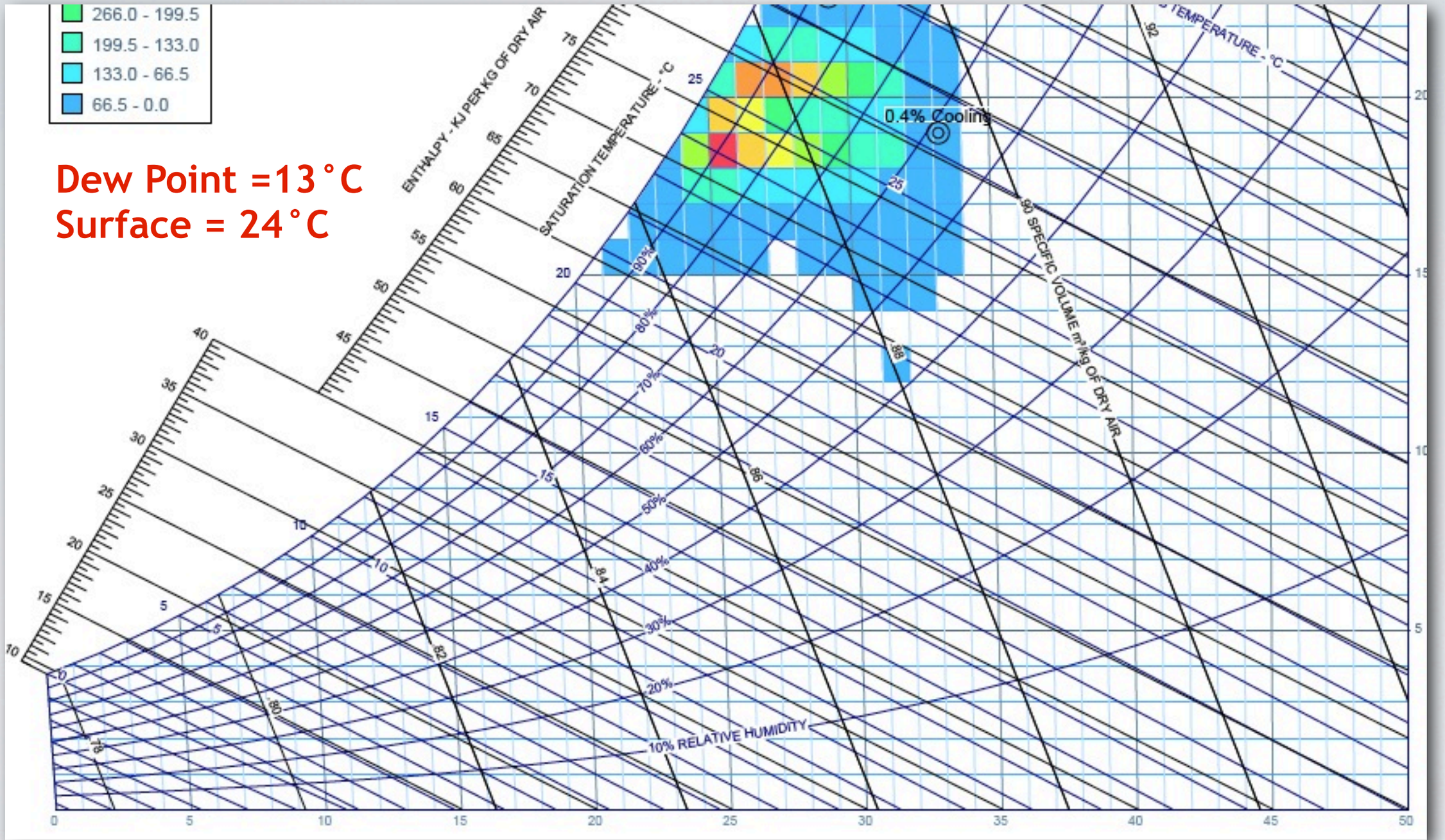
# Exercise - Finding the RH AT THE SURFACE, using a psychrometric chart



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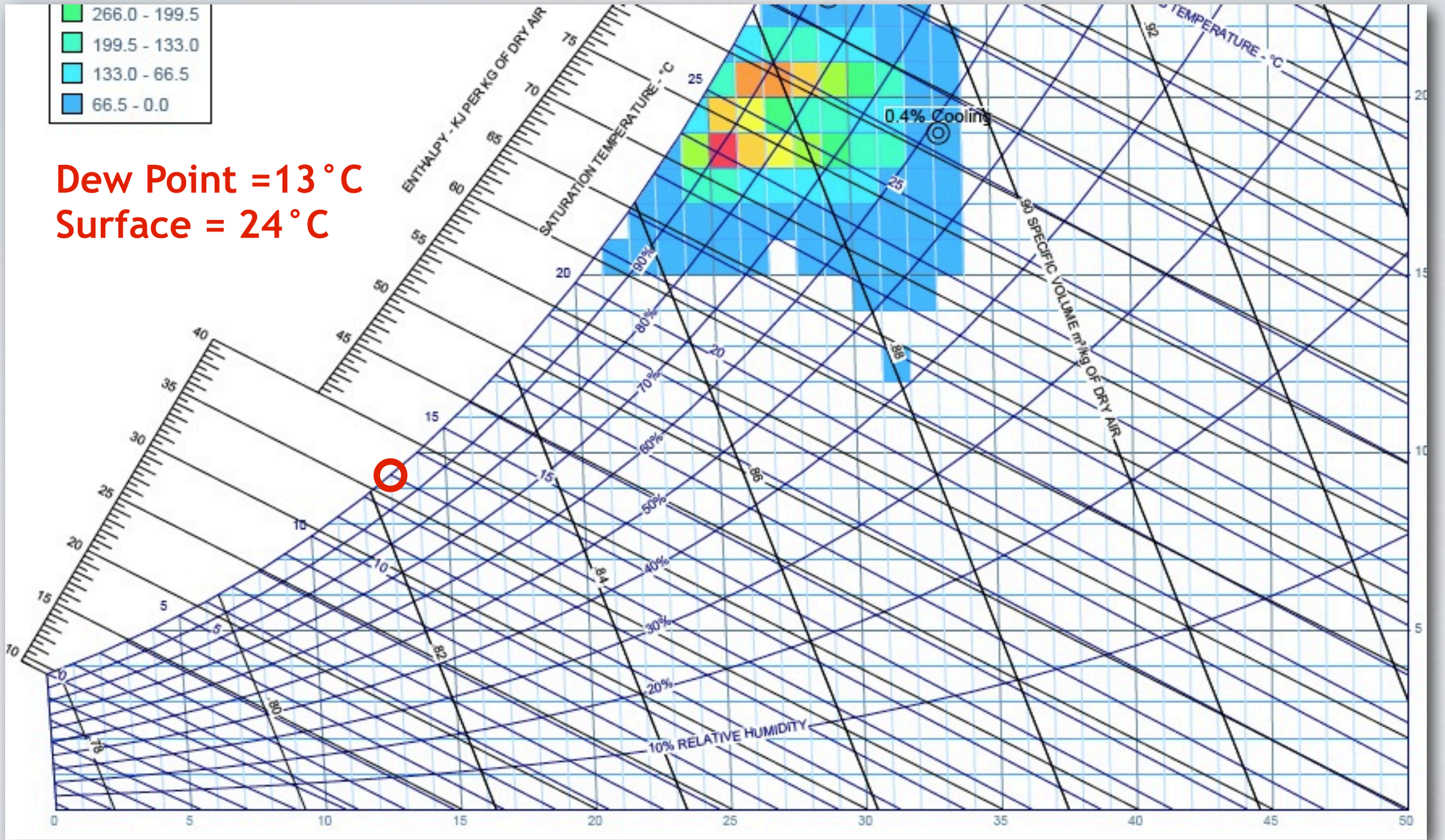

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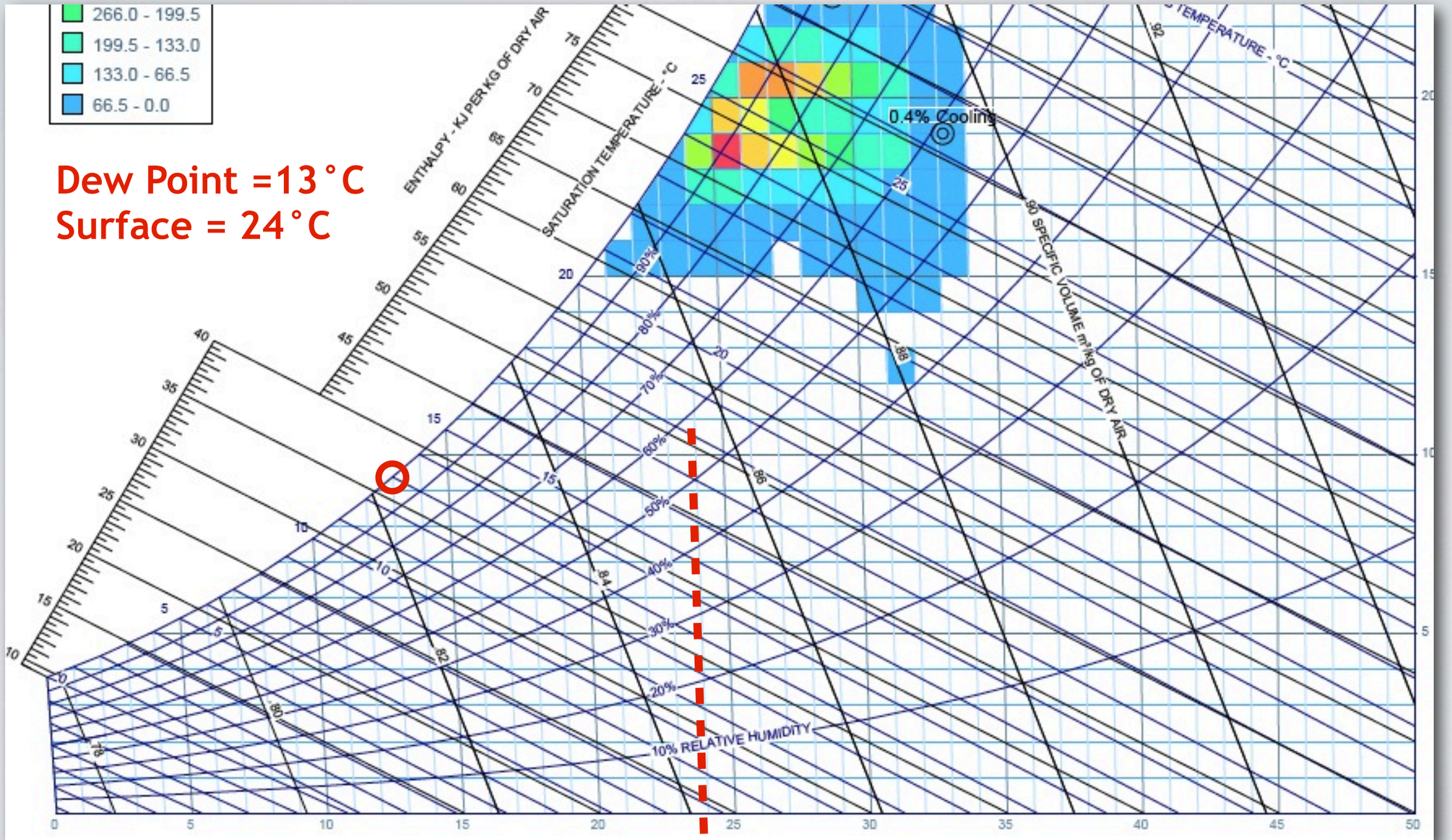

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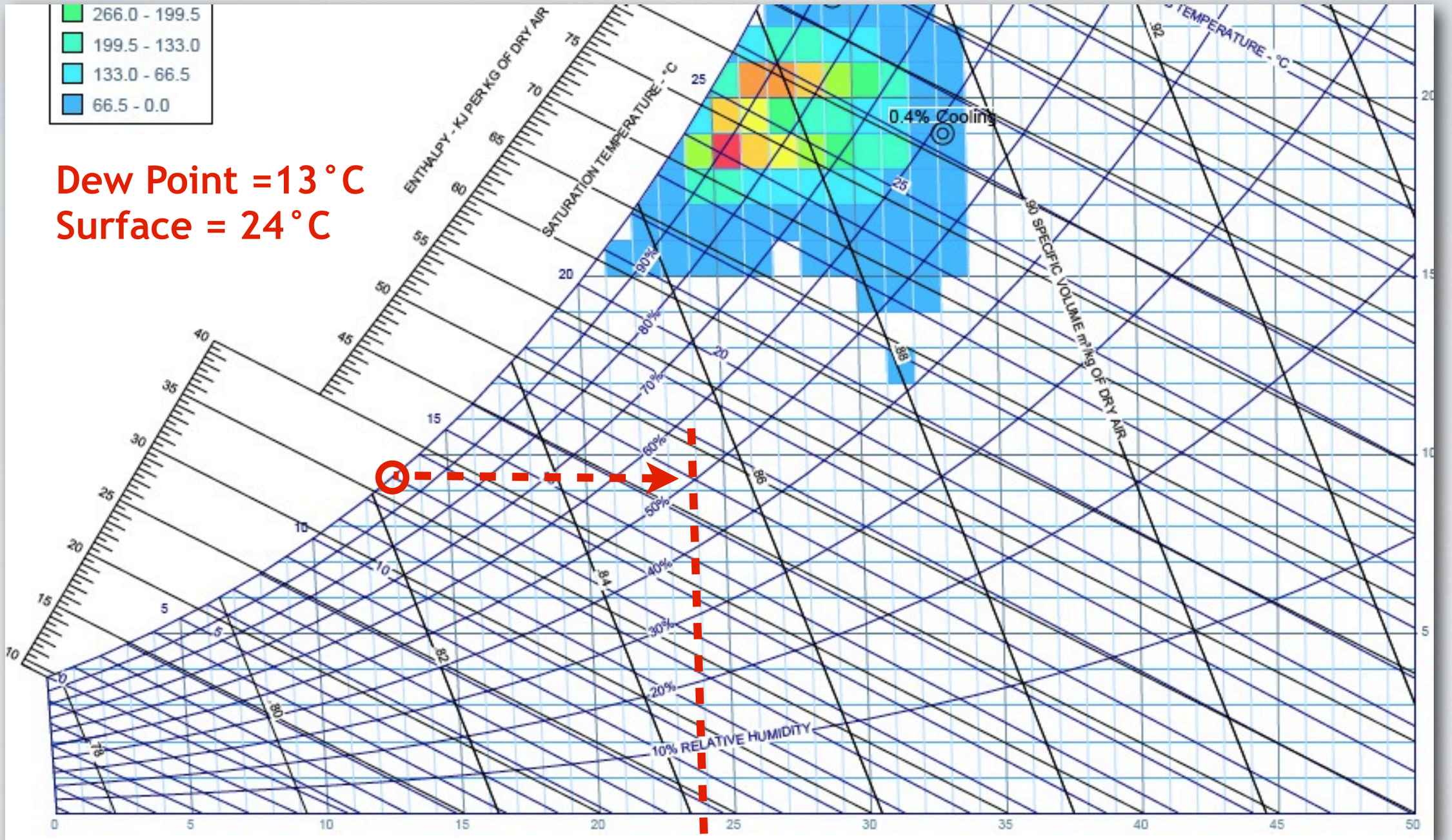

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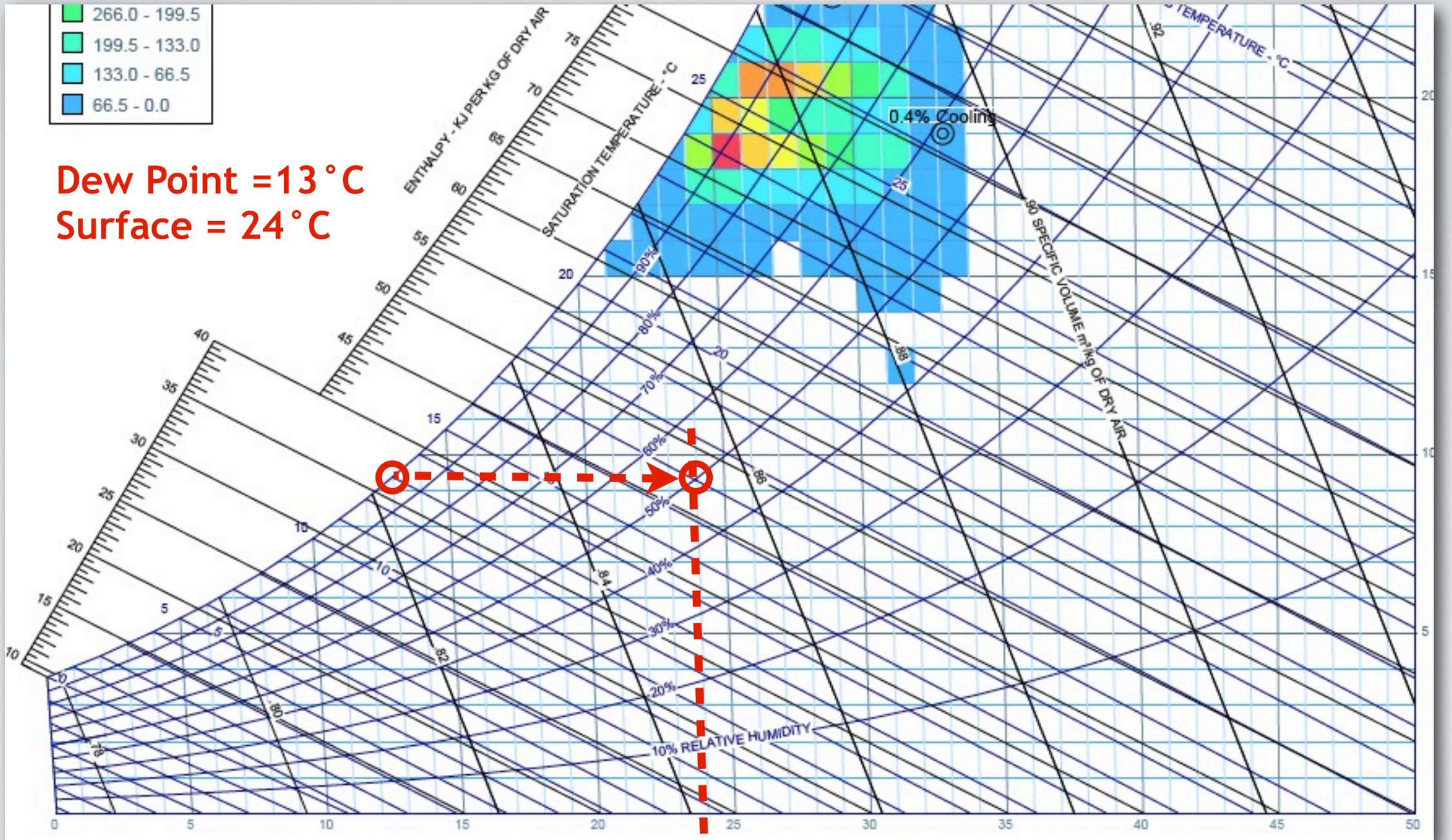

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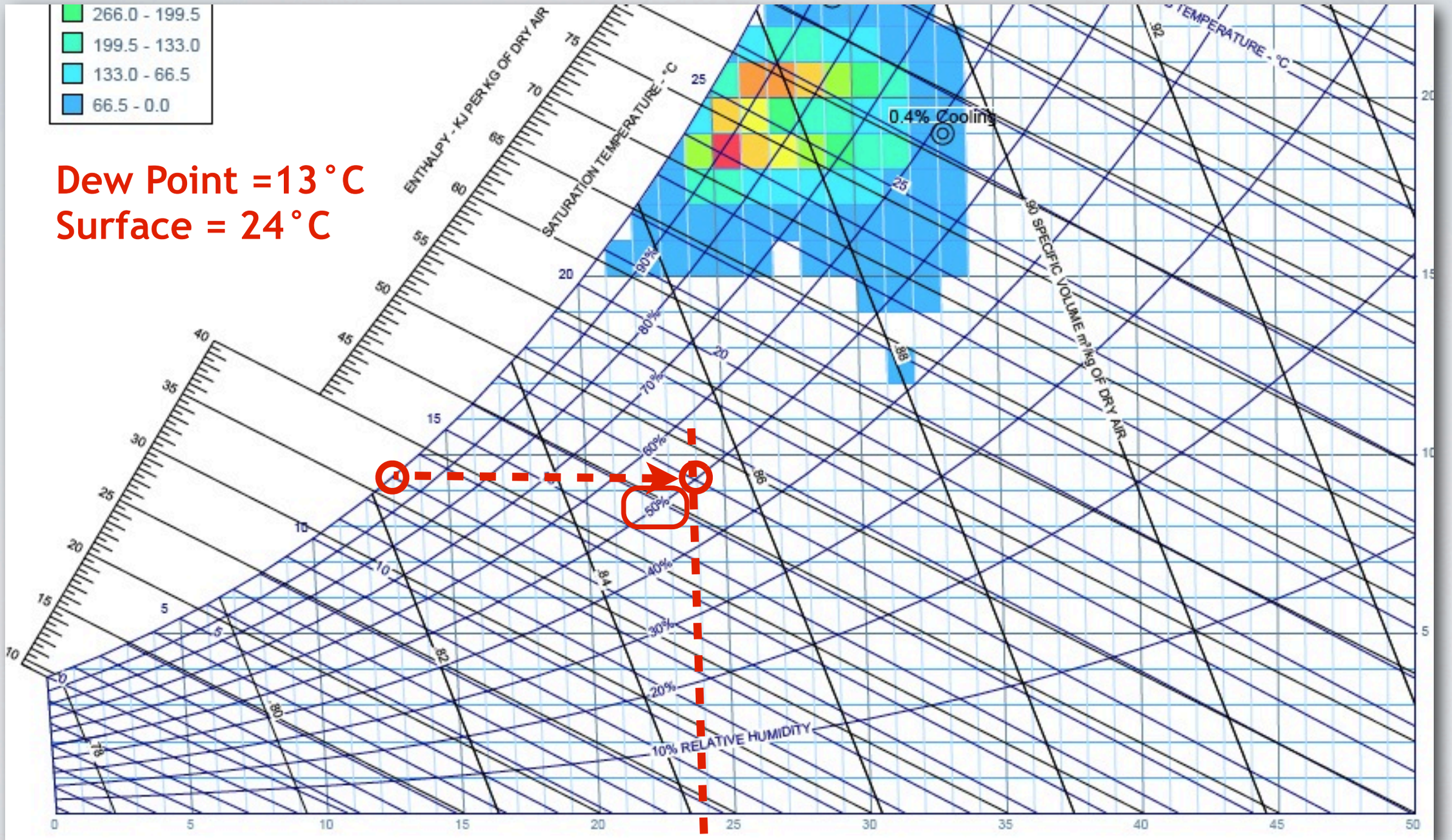

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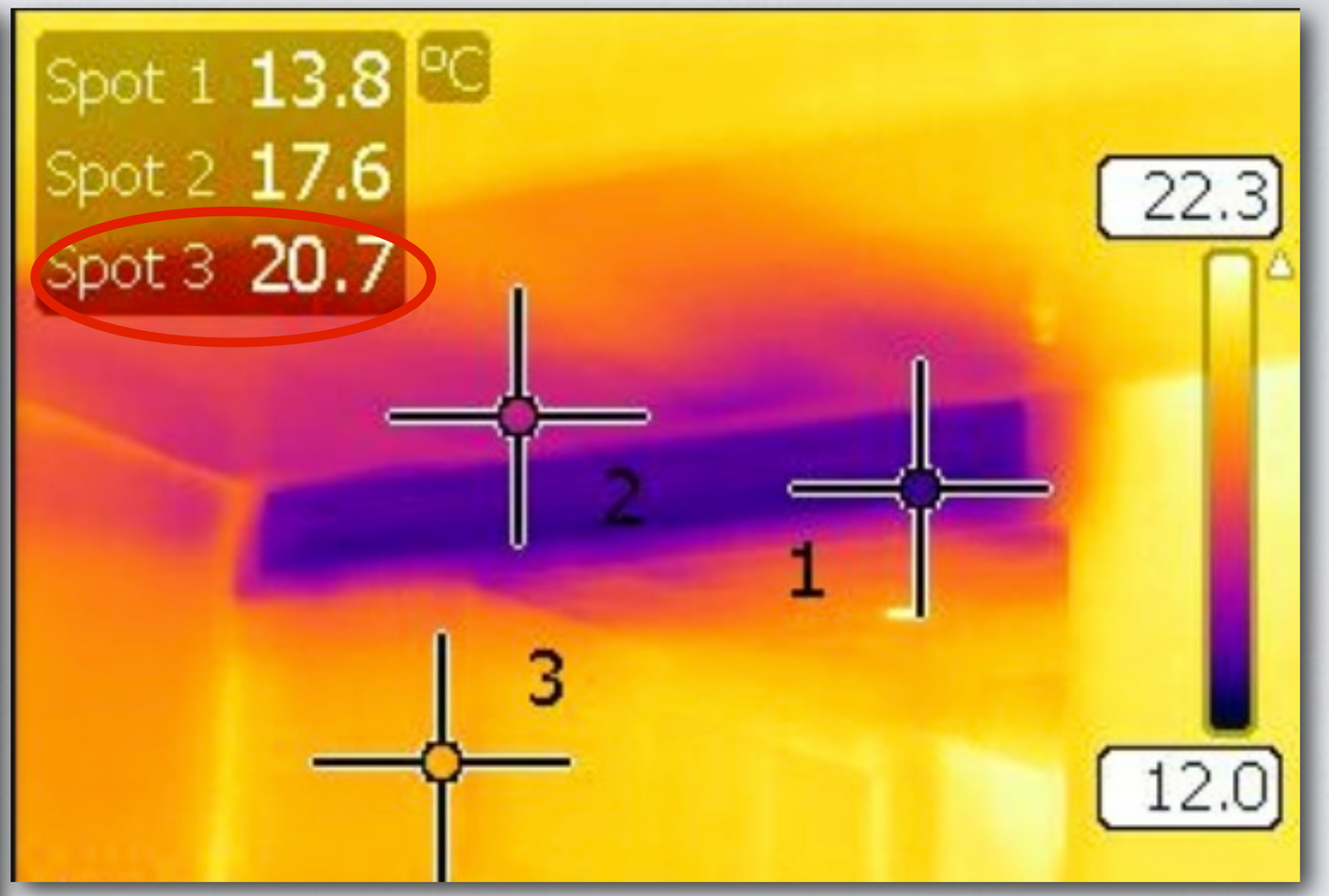

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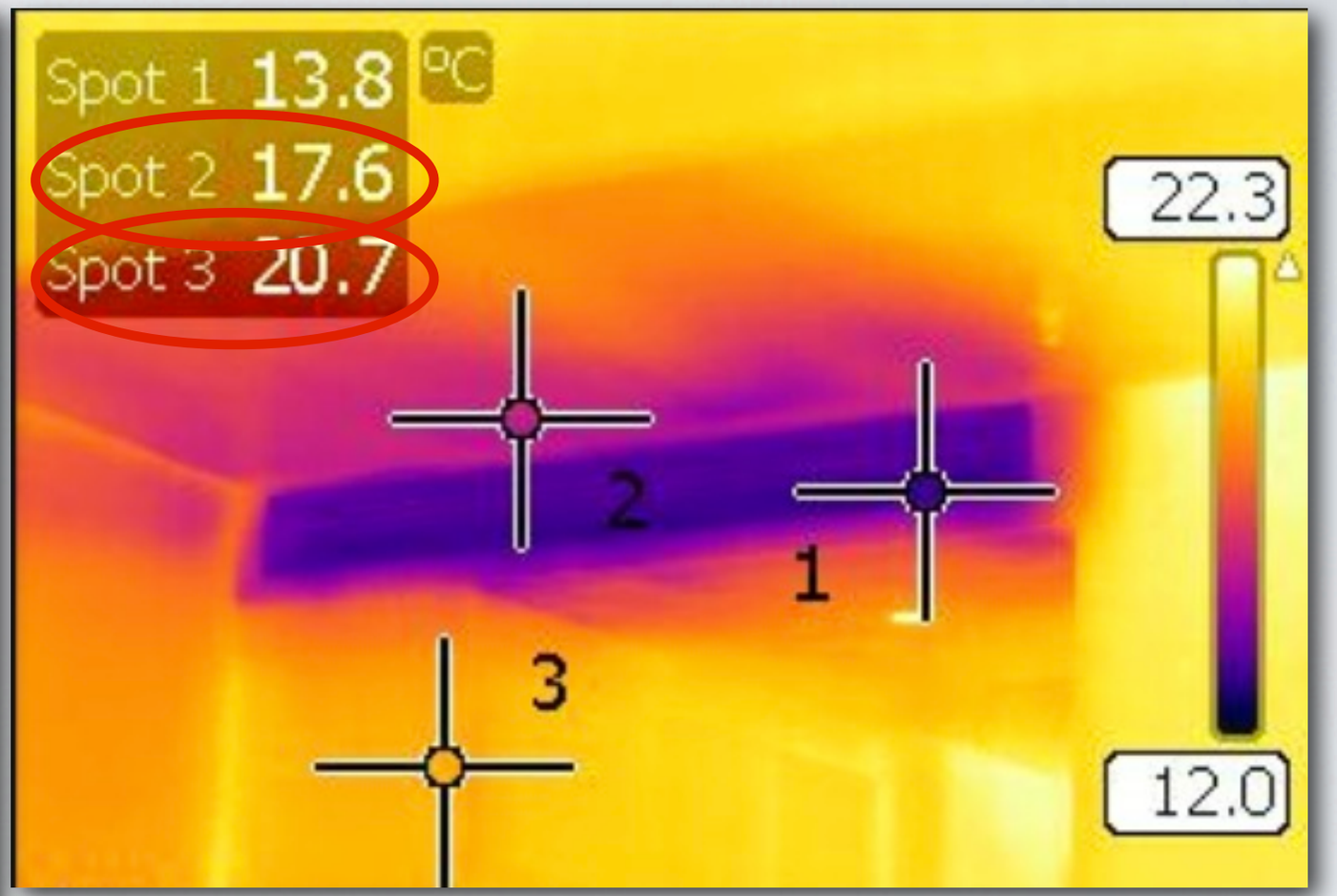

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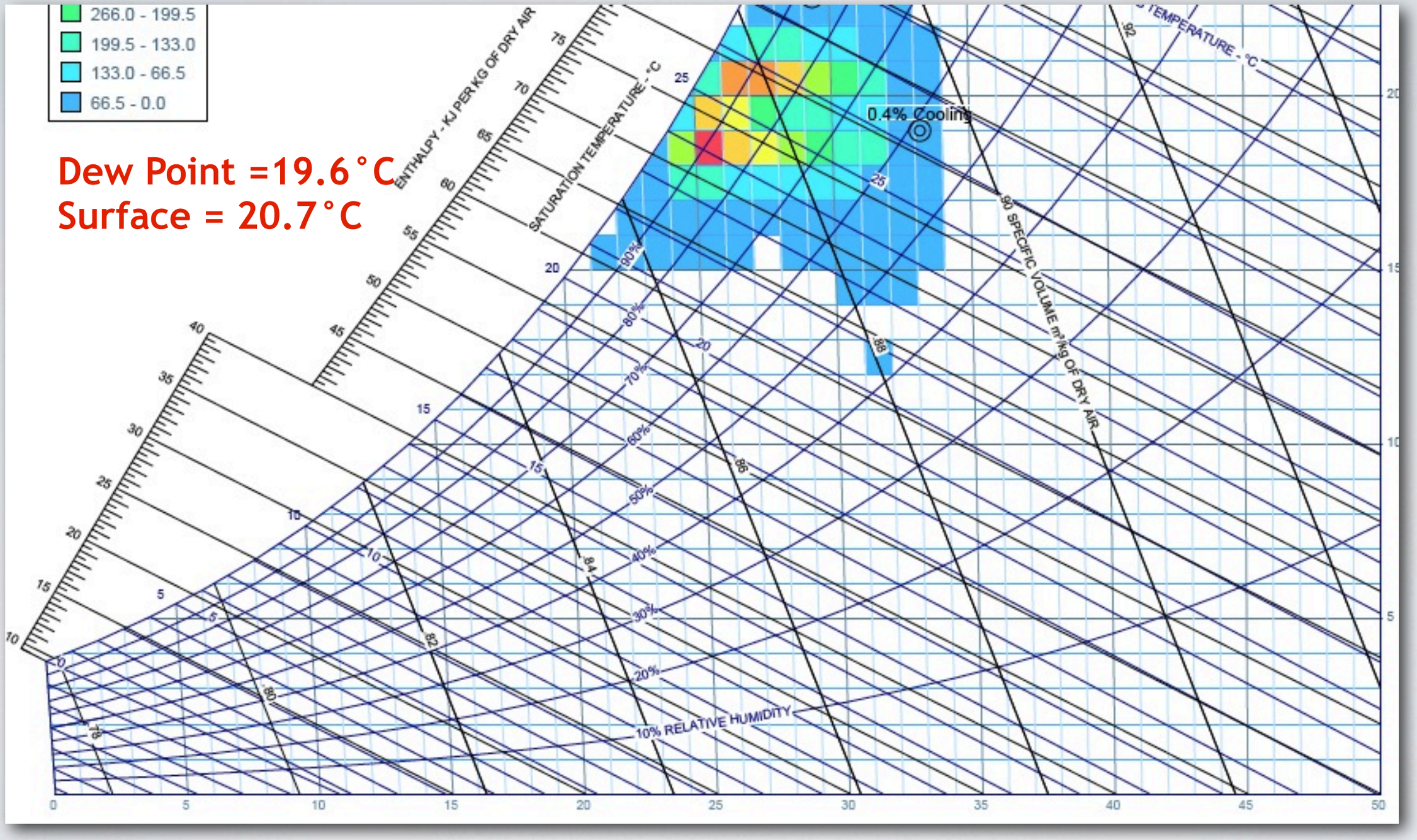

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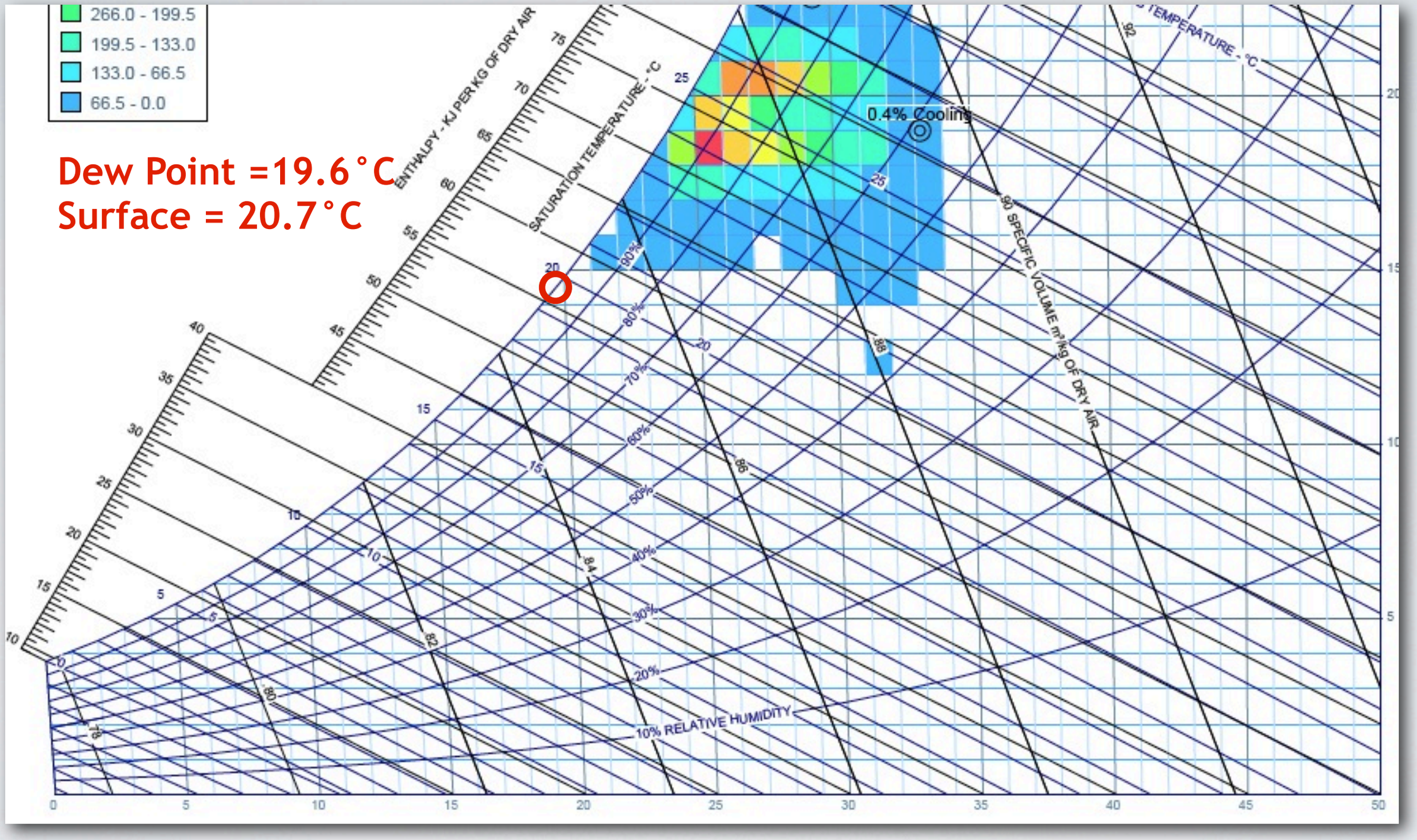

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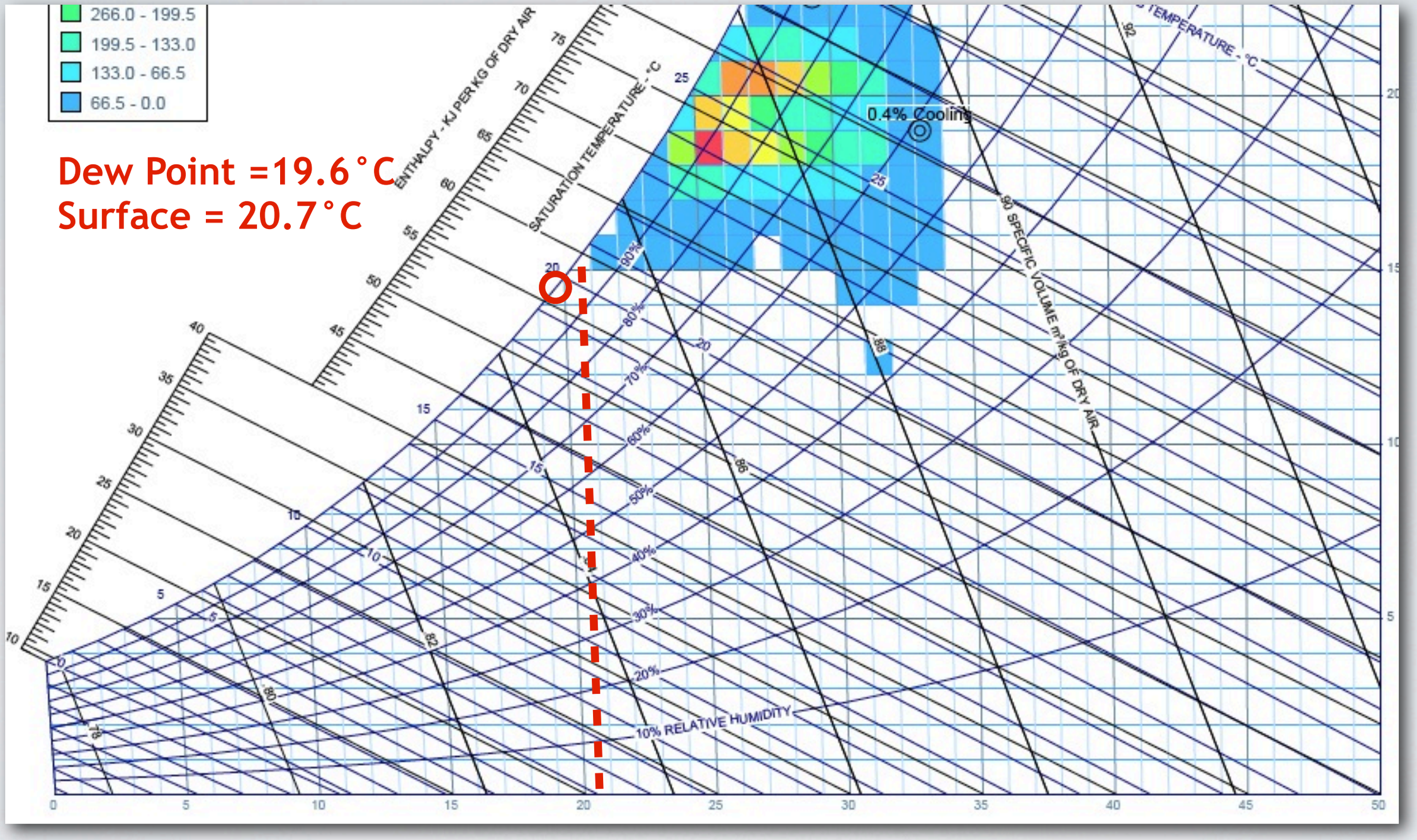

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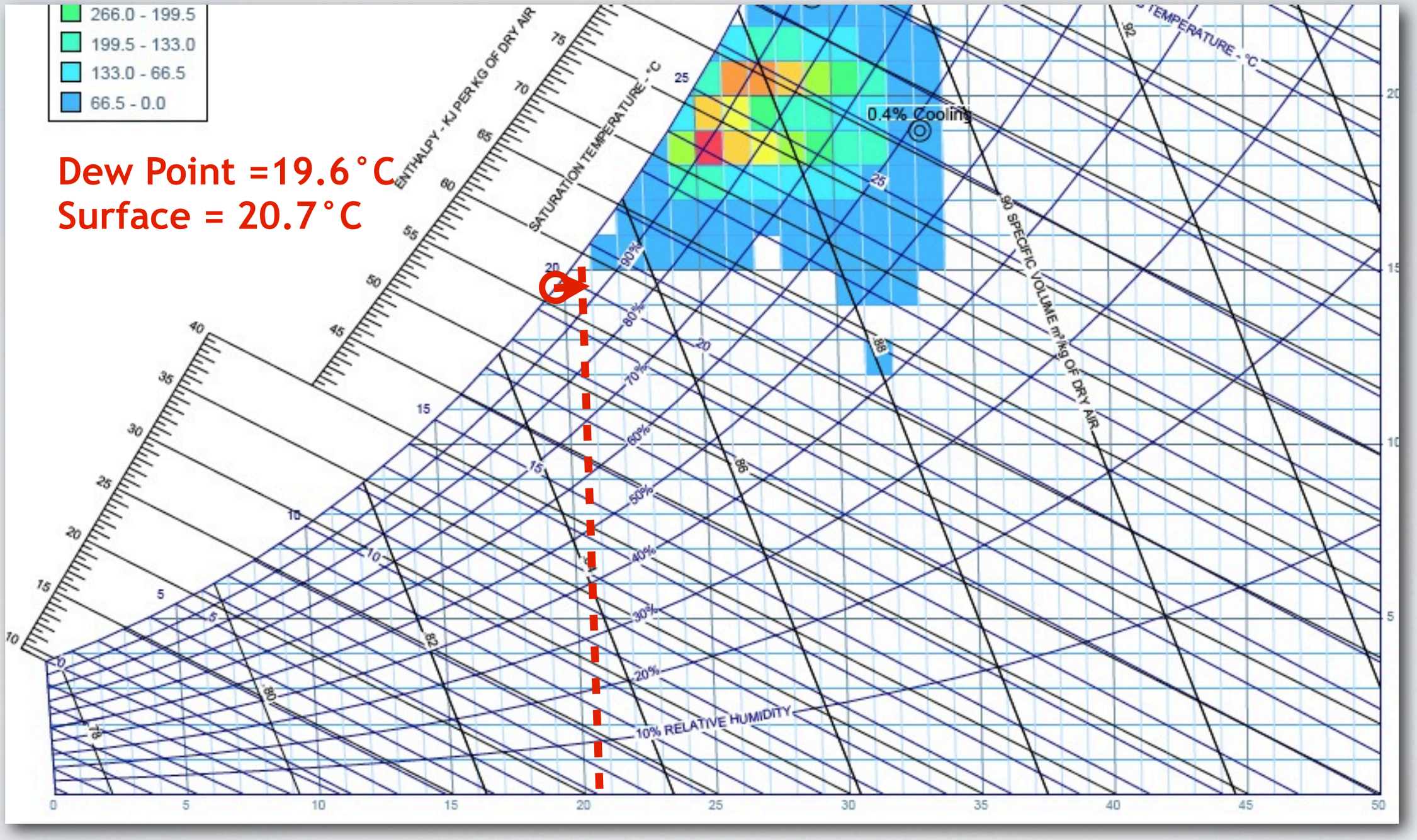

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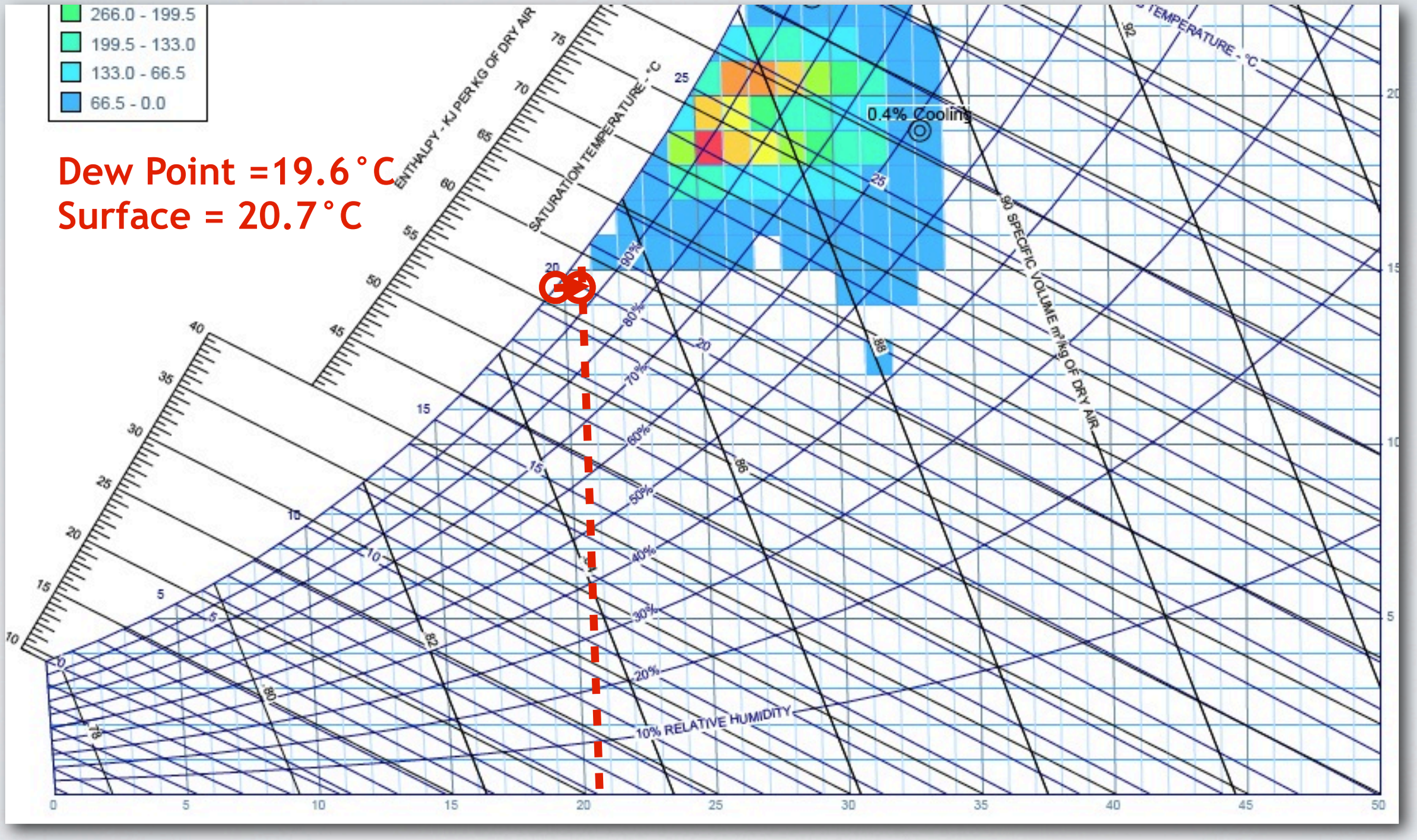

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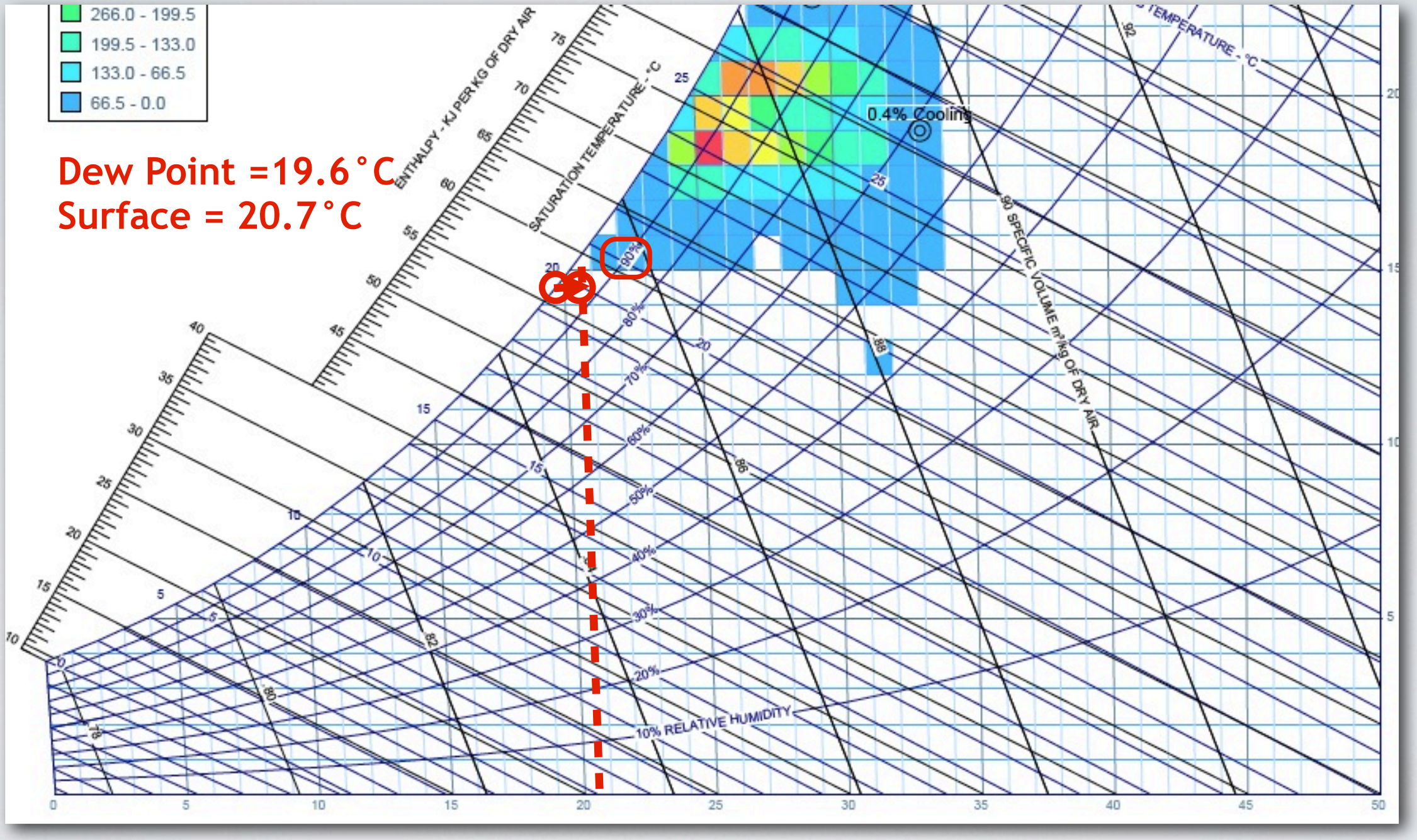

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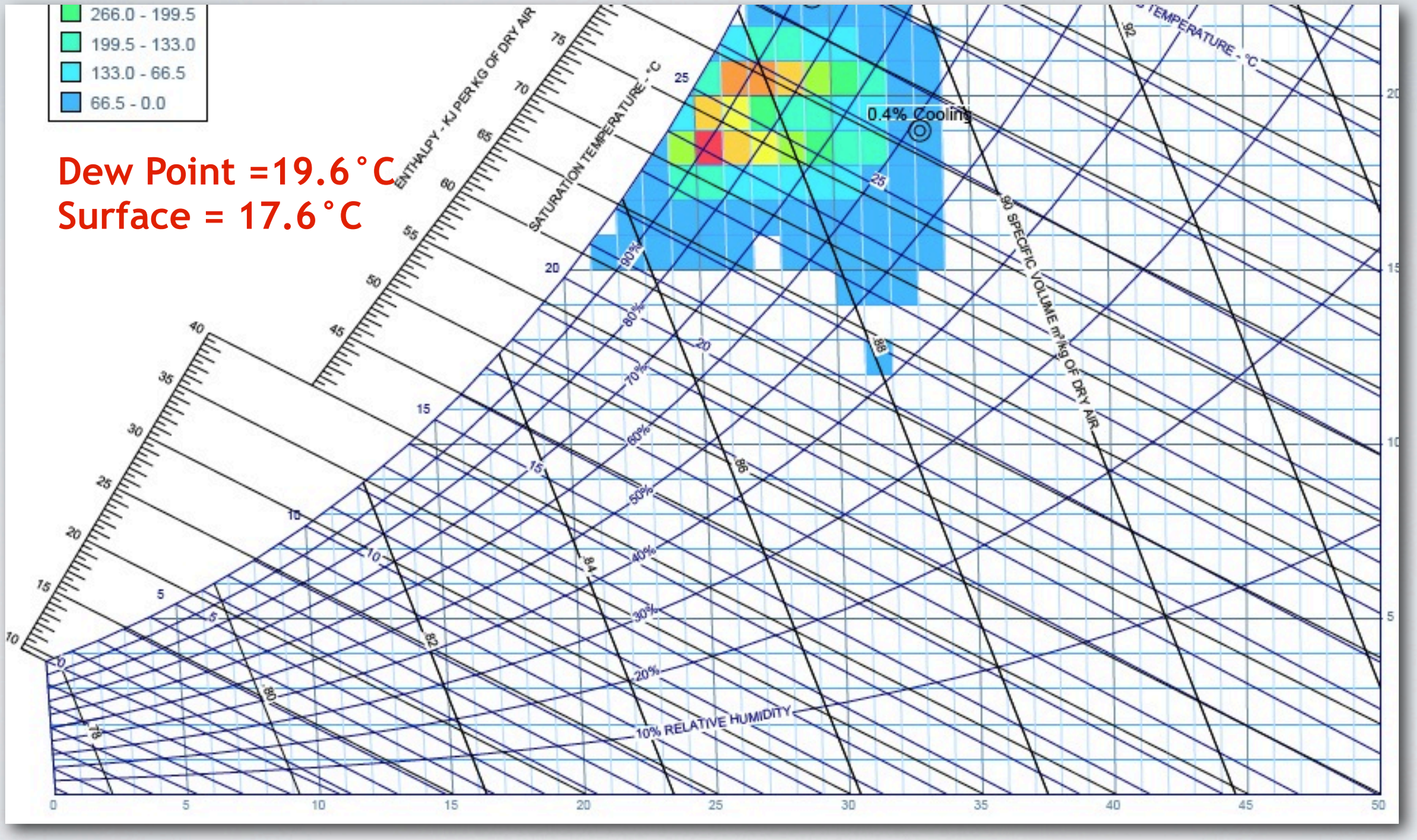

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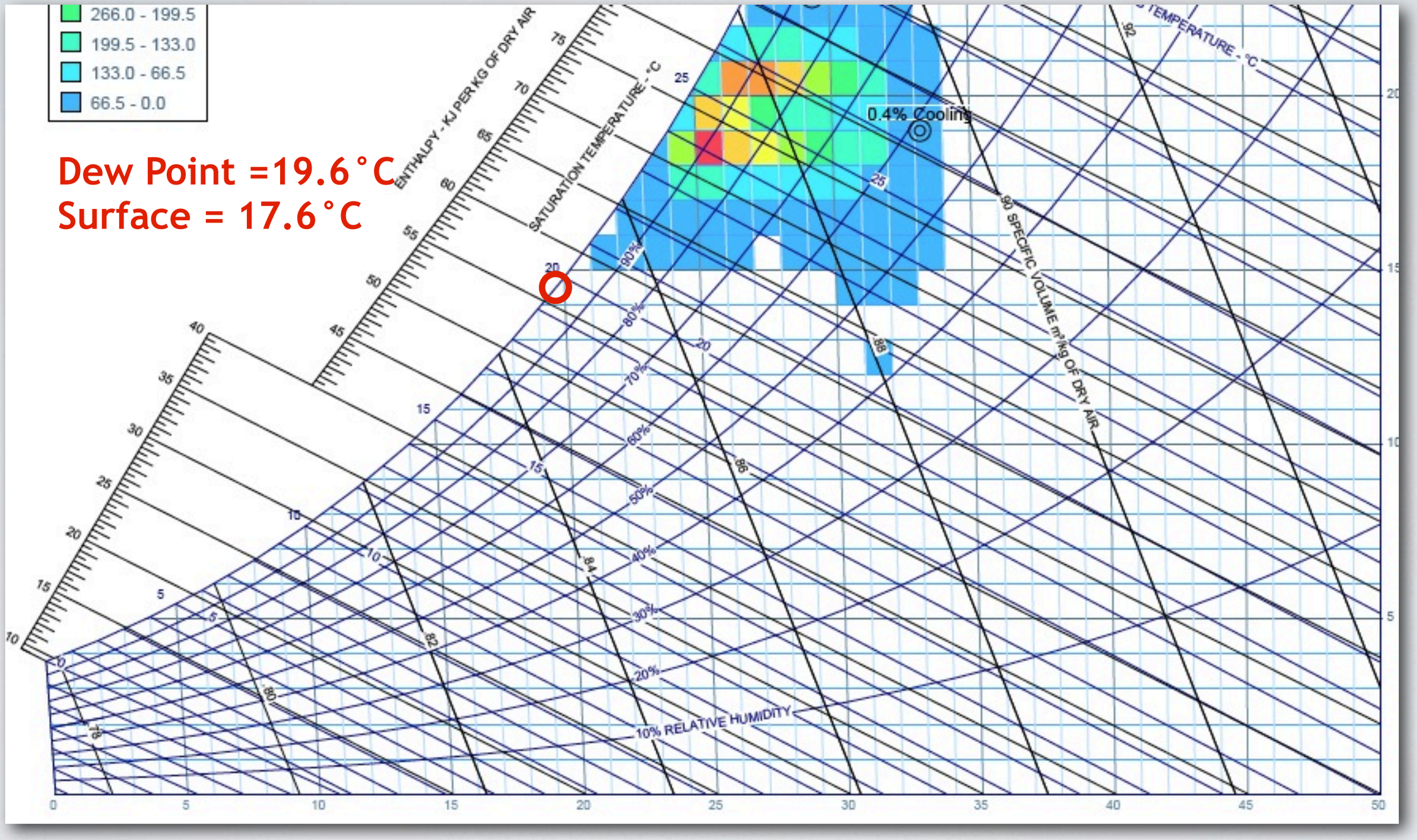

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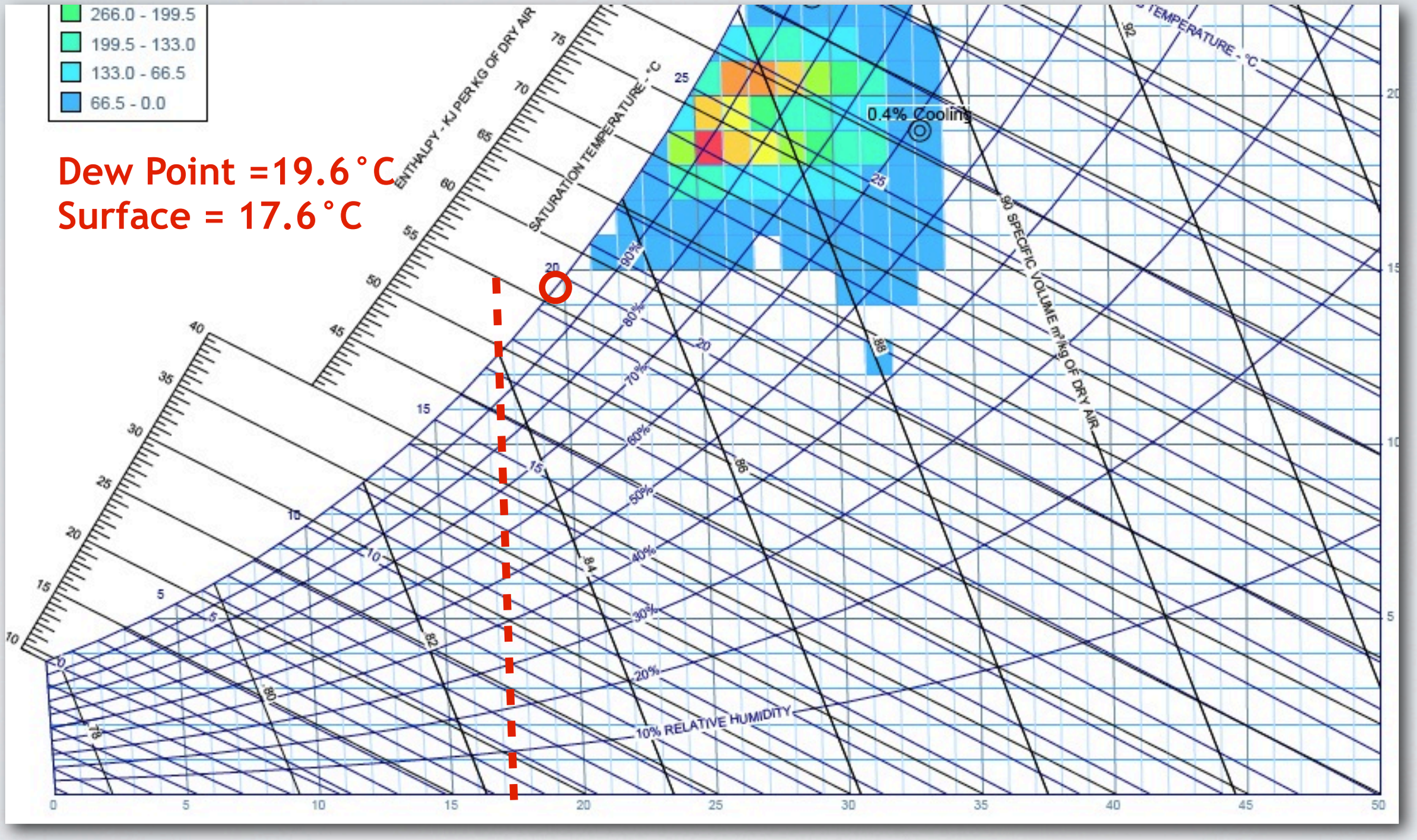

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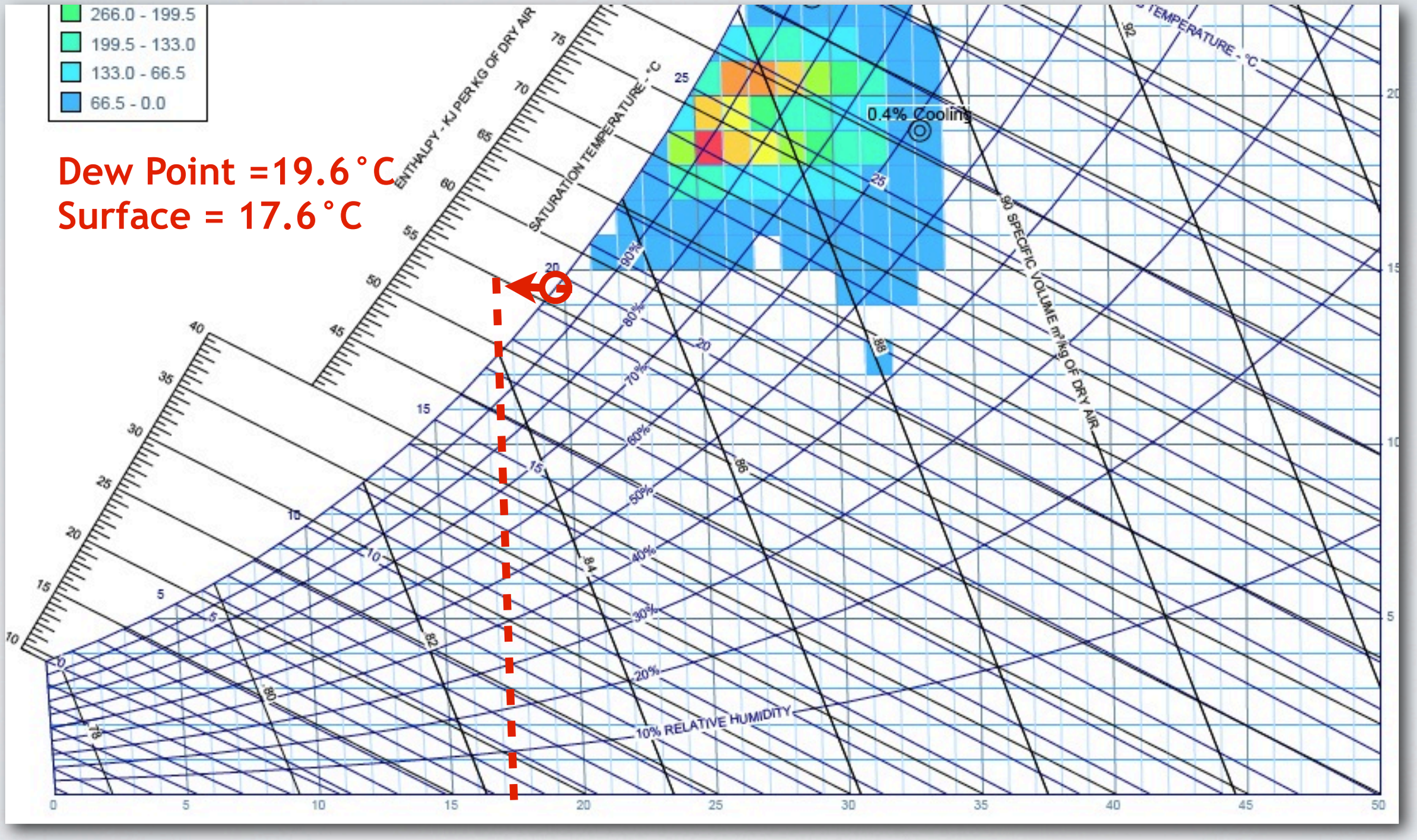

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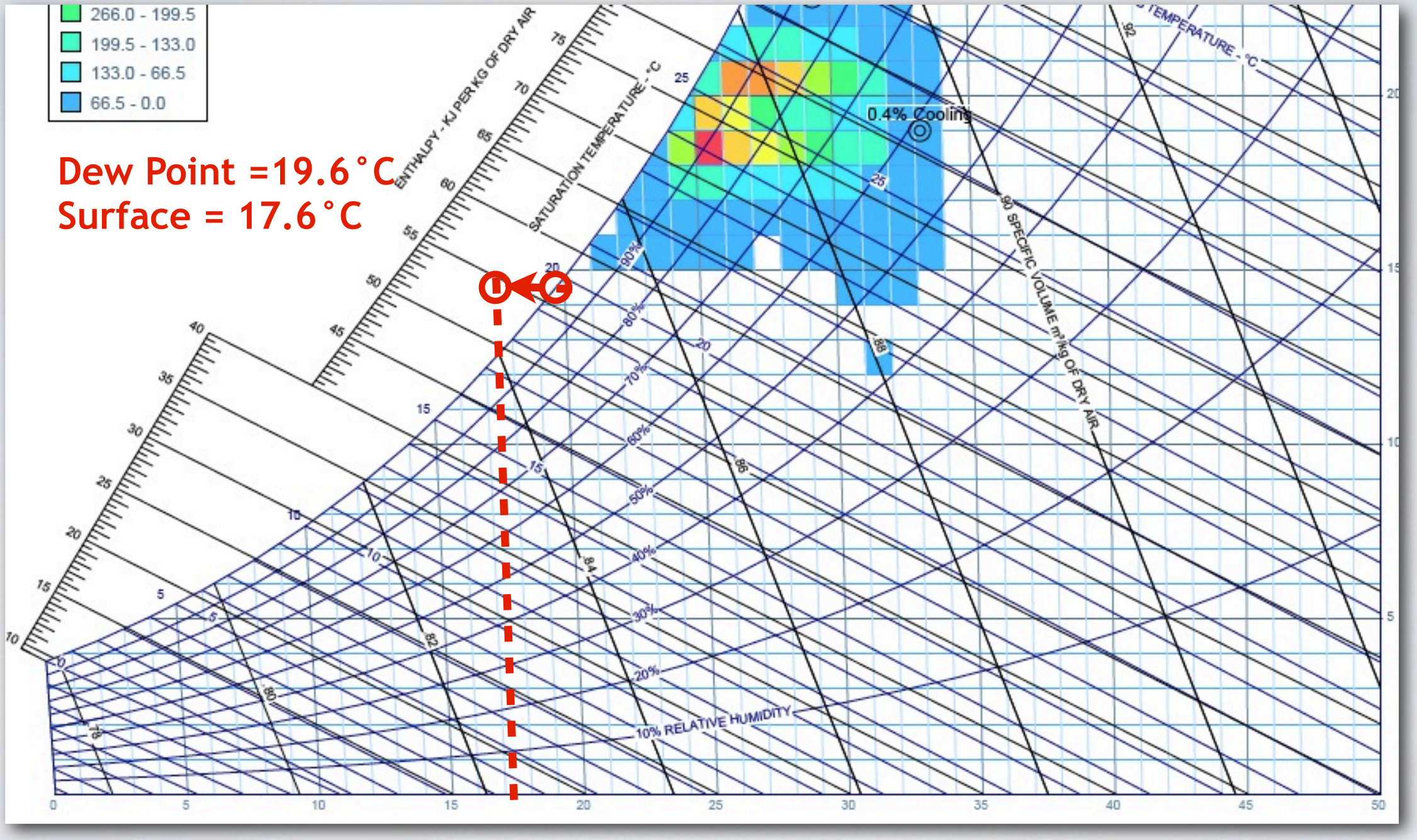

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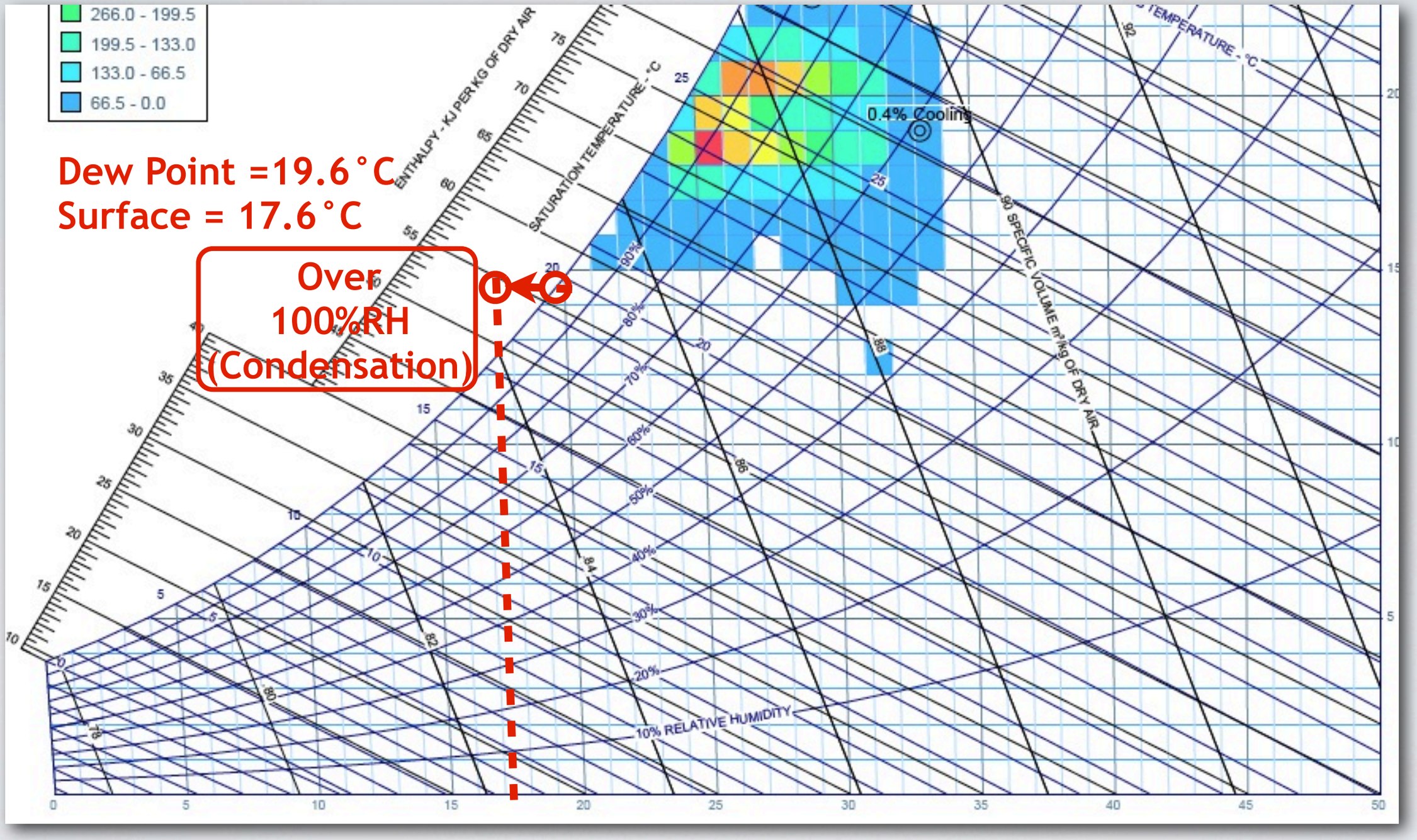
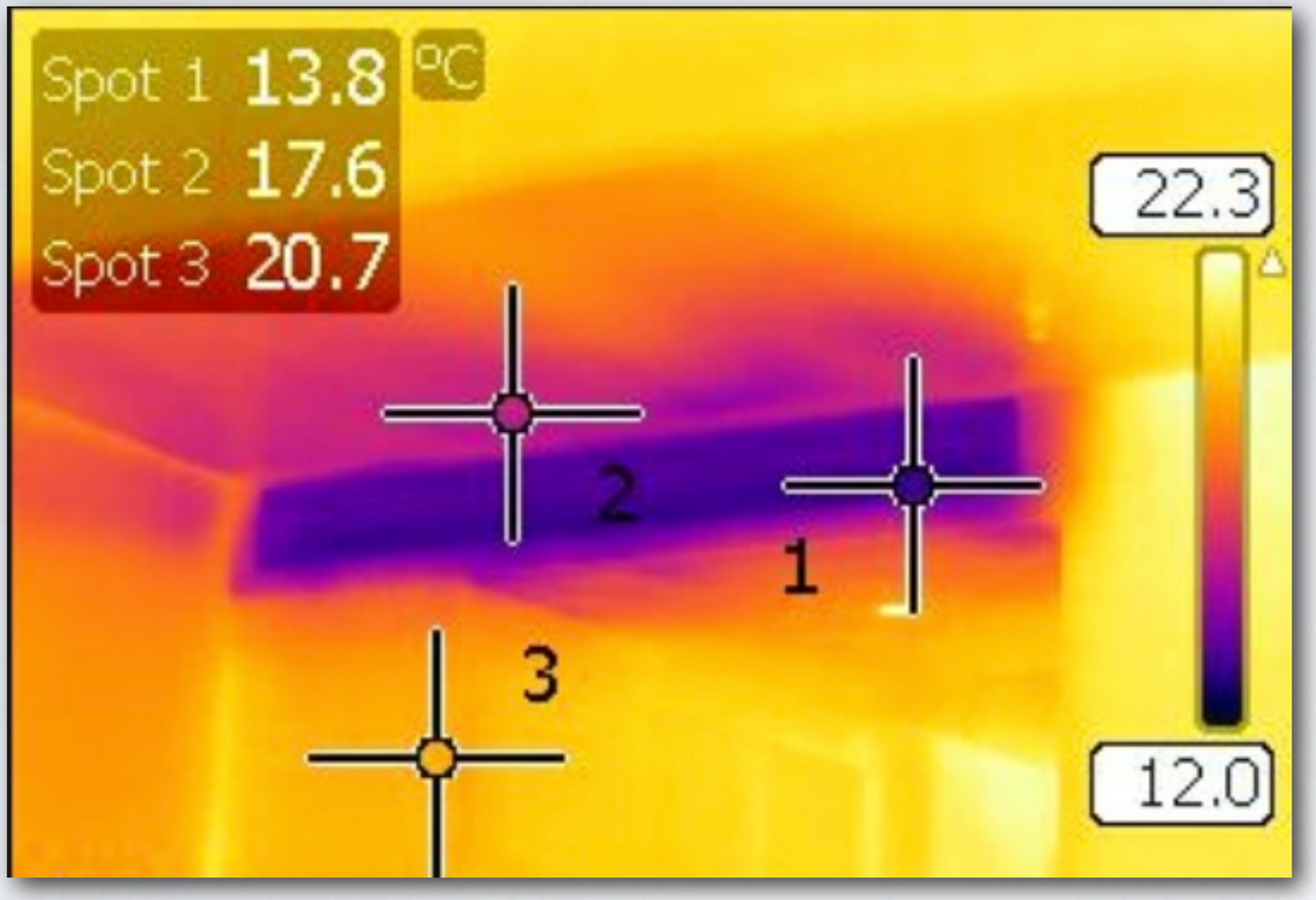


What is the mold risk for the walls of **Lew's hotel room** if the dew point stays at or above 19°C overnight (or over the weekends)?



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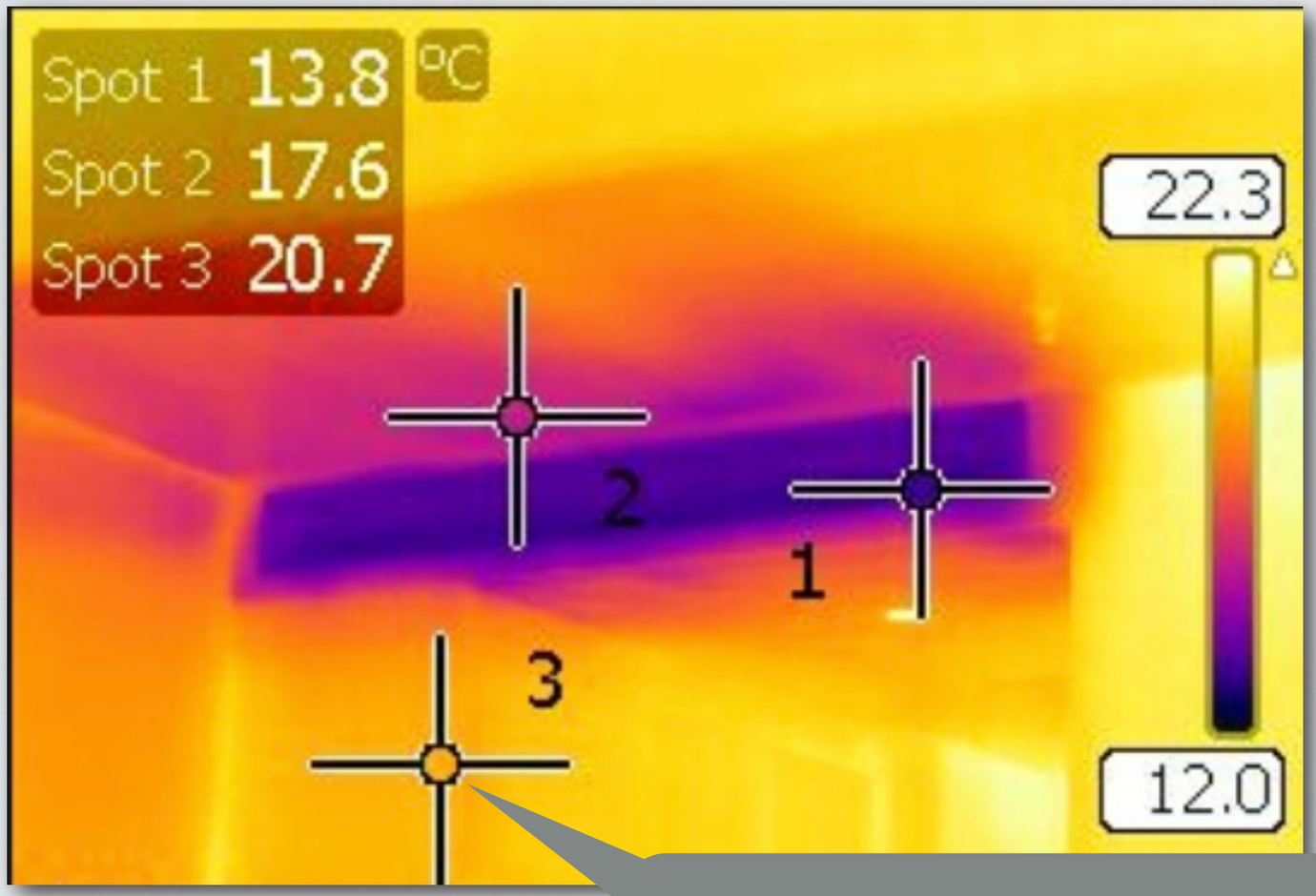


Surface RH = 95%
Mold Risk is high, over time

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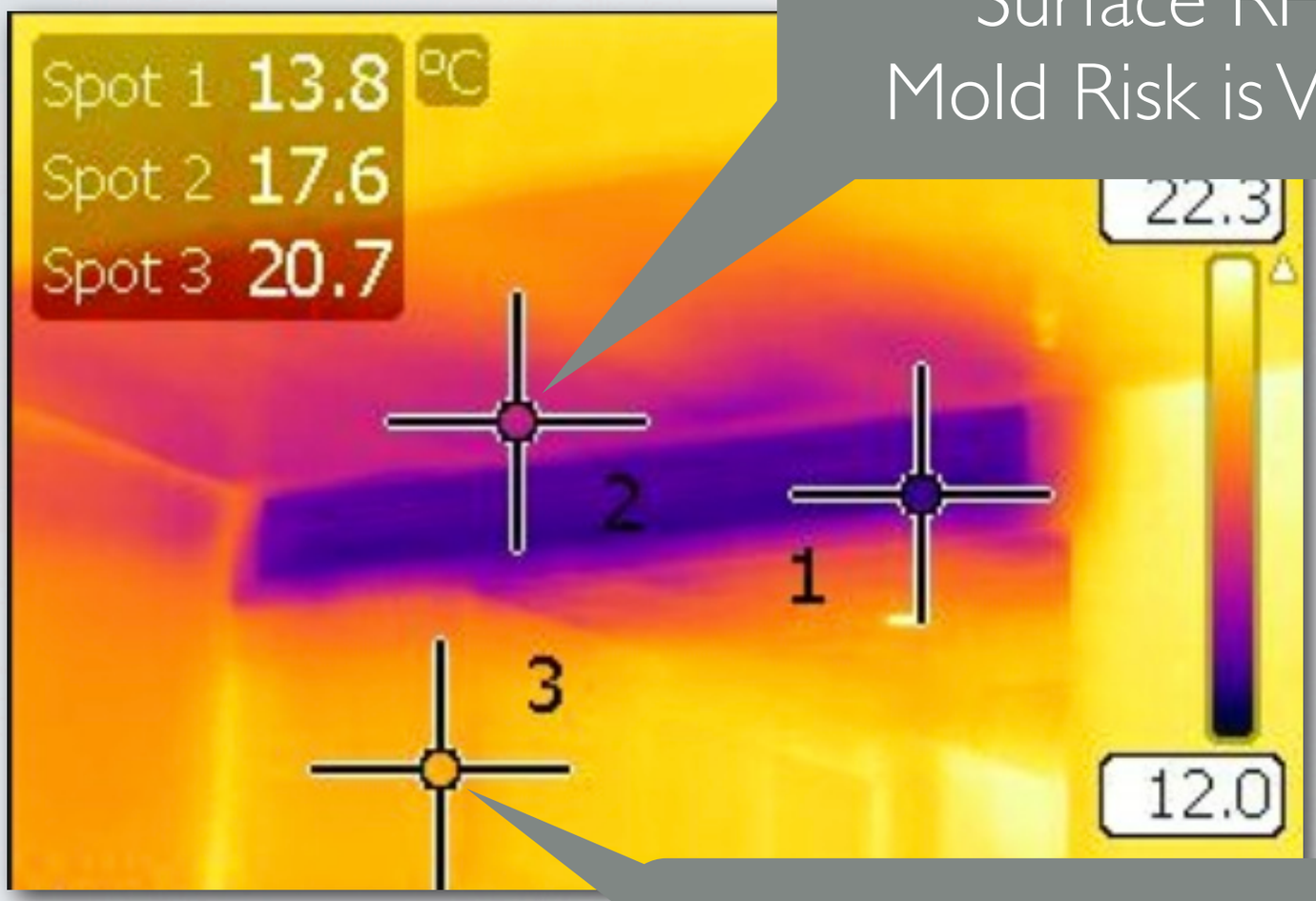


Surface RH = OVER 100%
Mold Risk is VERY high, over time

Surface RH = 95%
Mold Risk is high, over time

# Shanghai hotel room - 2010



# Shanghai hotel room - 2010



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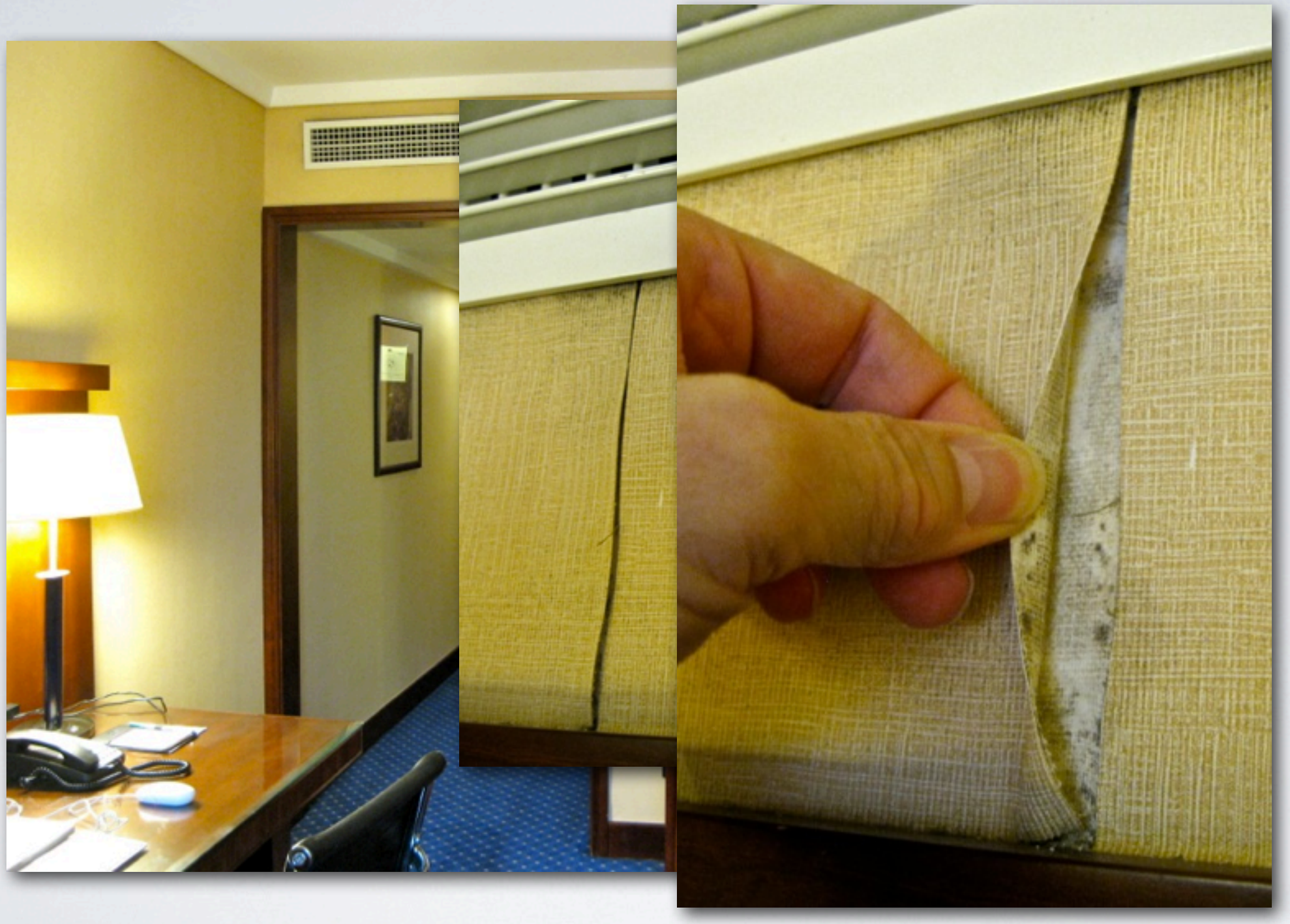

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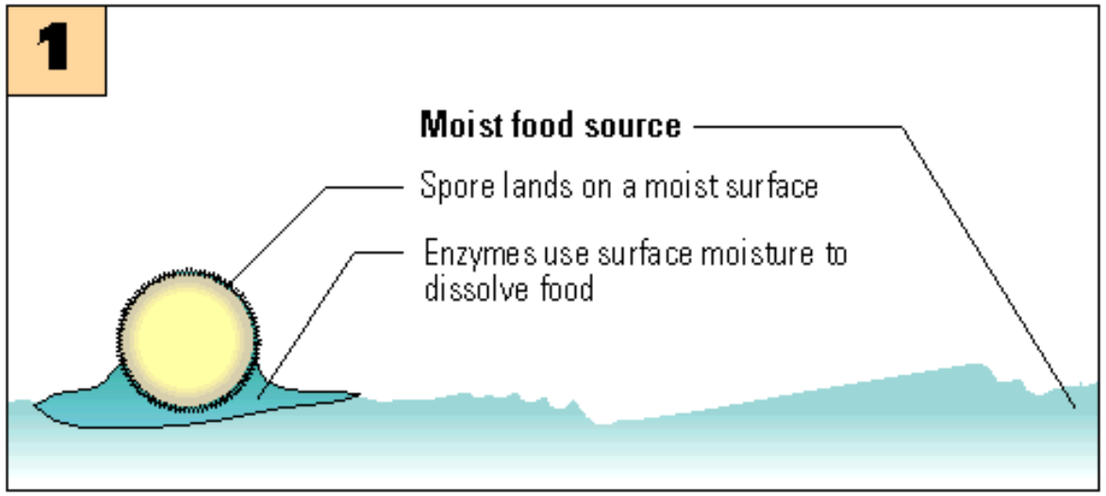
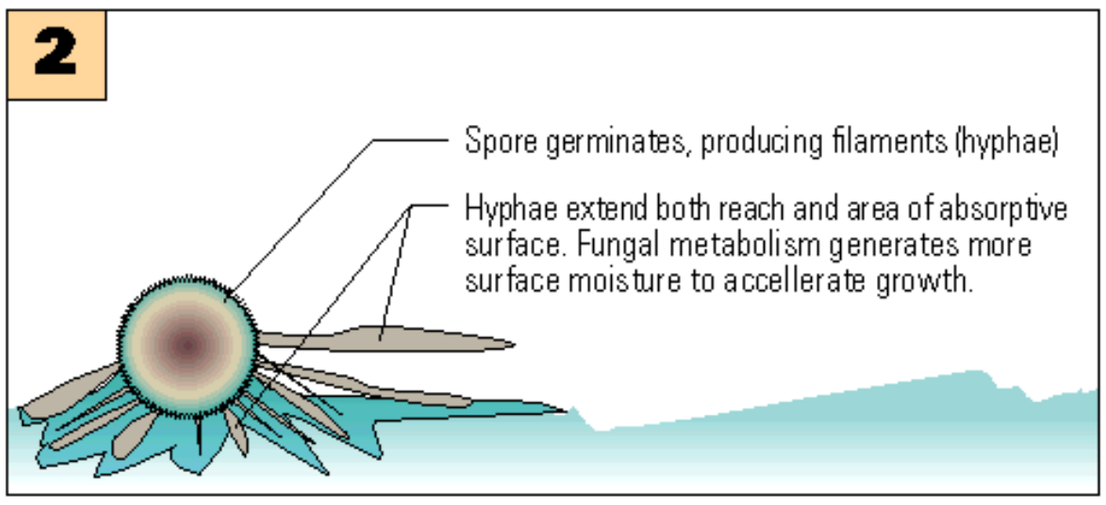
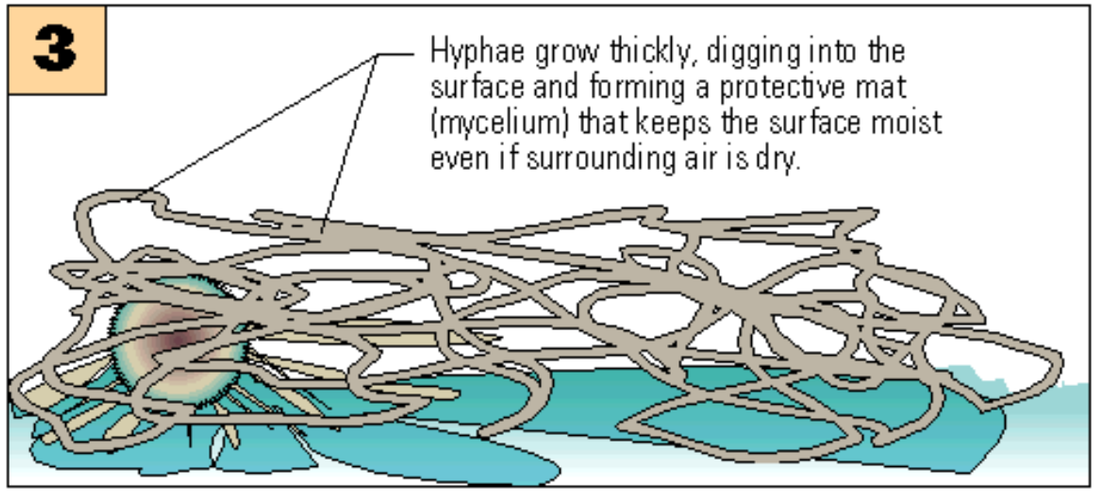
- Sealed the gaps between ducts and duct chase openings with sheet metal and spray foam.
- Installed desiccant DH unit which operates after AC units turn off at 5:00pm. DH keeps indoor air near or below 55°F dew point.
- No more comfort problems. Nearly no mold problems. There is a cost to operating the desiccant DH, but much less than operating cooling units.

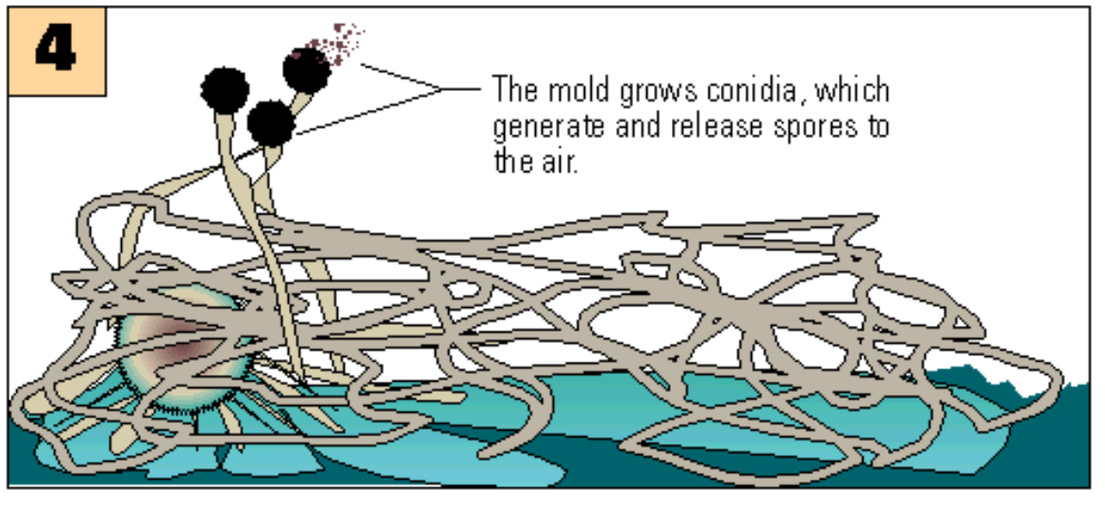
# Understanding mold growth in buildings

## Mold only cares about moisture in it's food - not RH

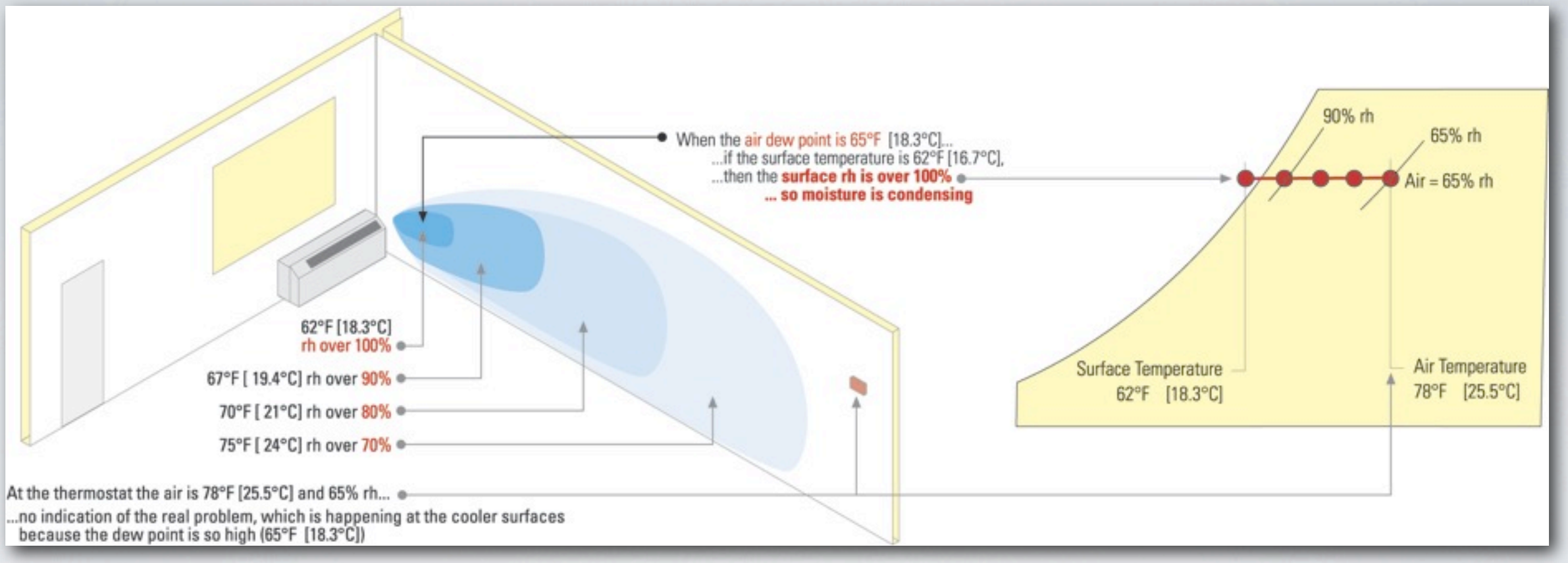


# RH in the air.. vs. RH at the surface



# Moldy building example



# Moldy building example



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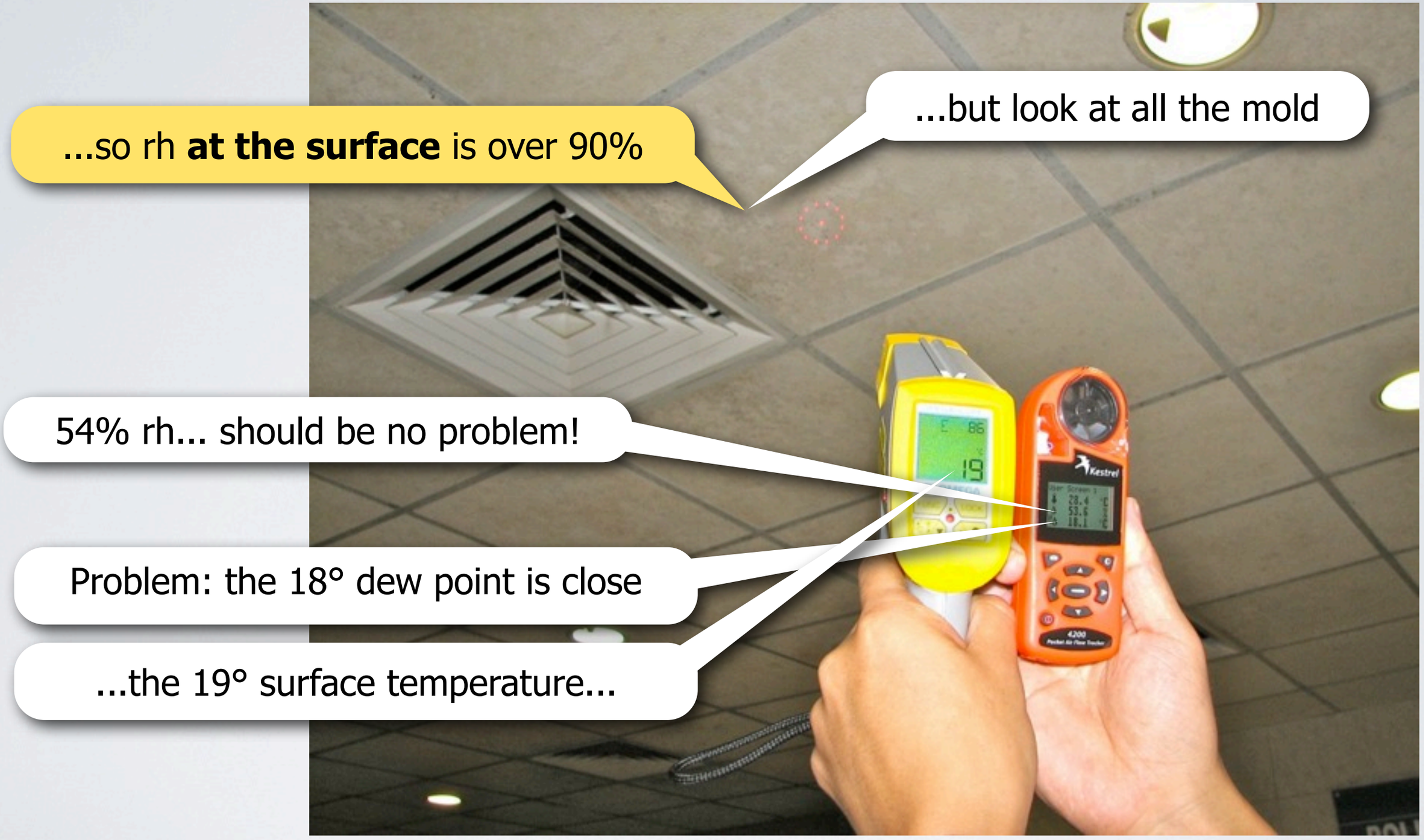


# Mold growth is greatest on coldest surfaces



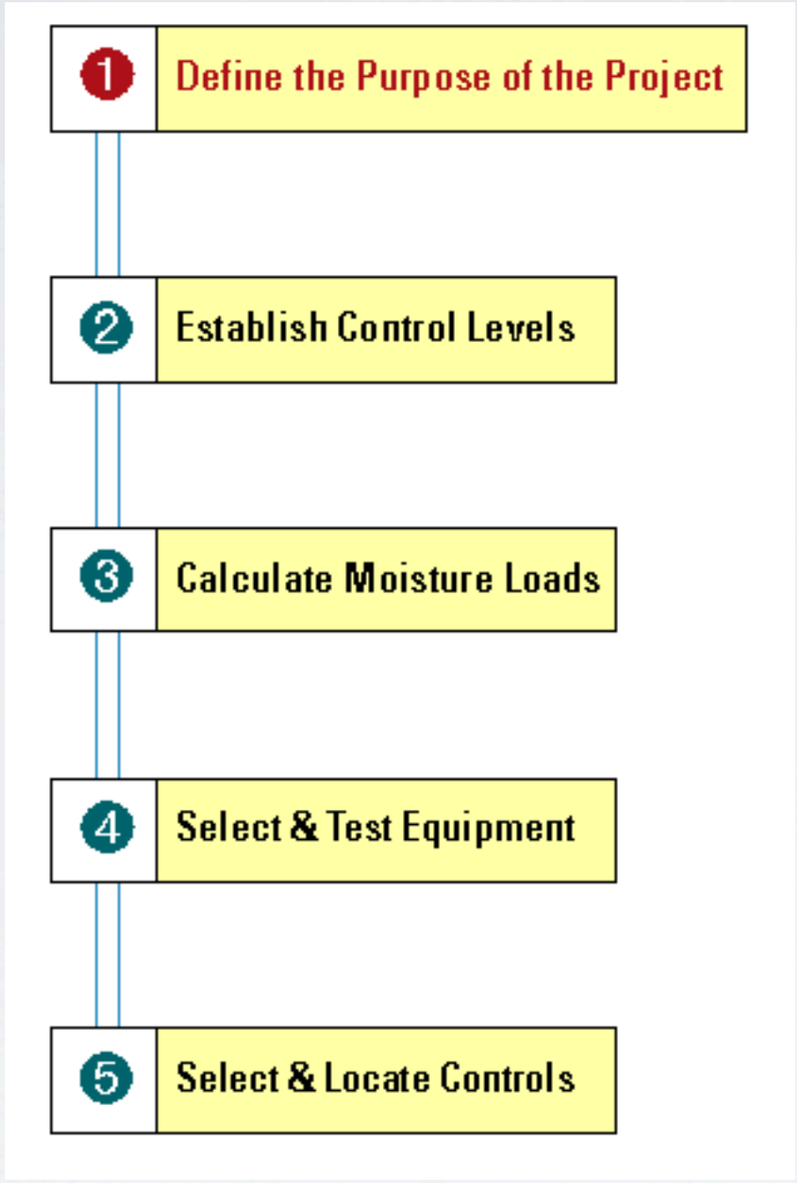
# Too much cooling leads to moisture absorption, and then to mold



## Section 2a of 3

# Humidity Control Design

# Designing for humidity control - 5-part sequence



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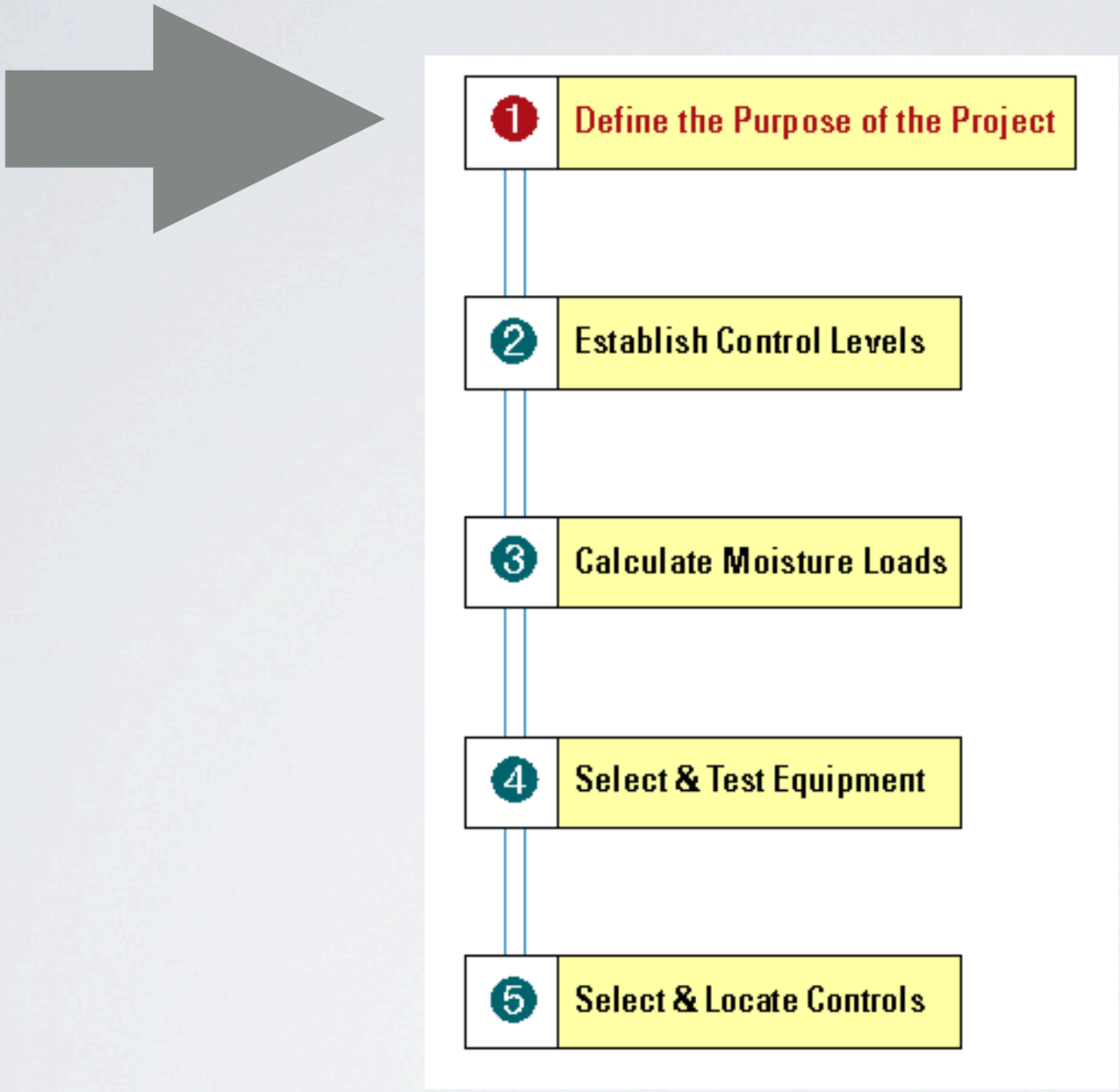


# Defining the purpose of the project

**Why insist the client define the purpose?**

- If client has no problem... no reason to spend money on humidity control.
- If consequences are not defined… impossible to say what that budget must be… and impossible to make rational decisions on the owner's behalf.

A good project purpose definition includes what...

- Results are expected
- Happens when the results are NOT achieved
- Shortcoming is acceptable

# Poor project definition

"Control the humidity within the usual limits for a hotel"

Does not define what the system must accomplish...

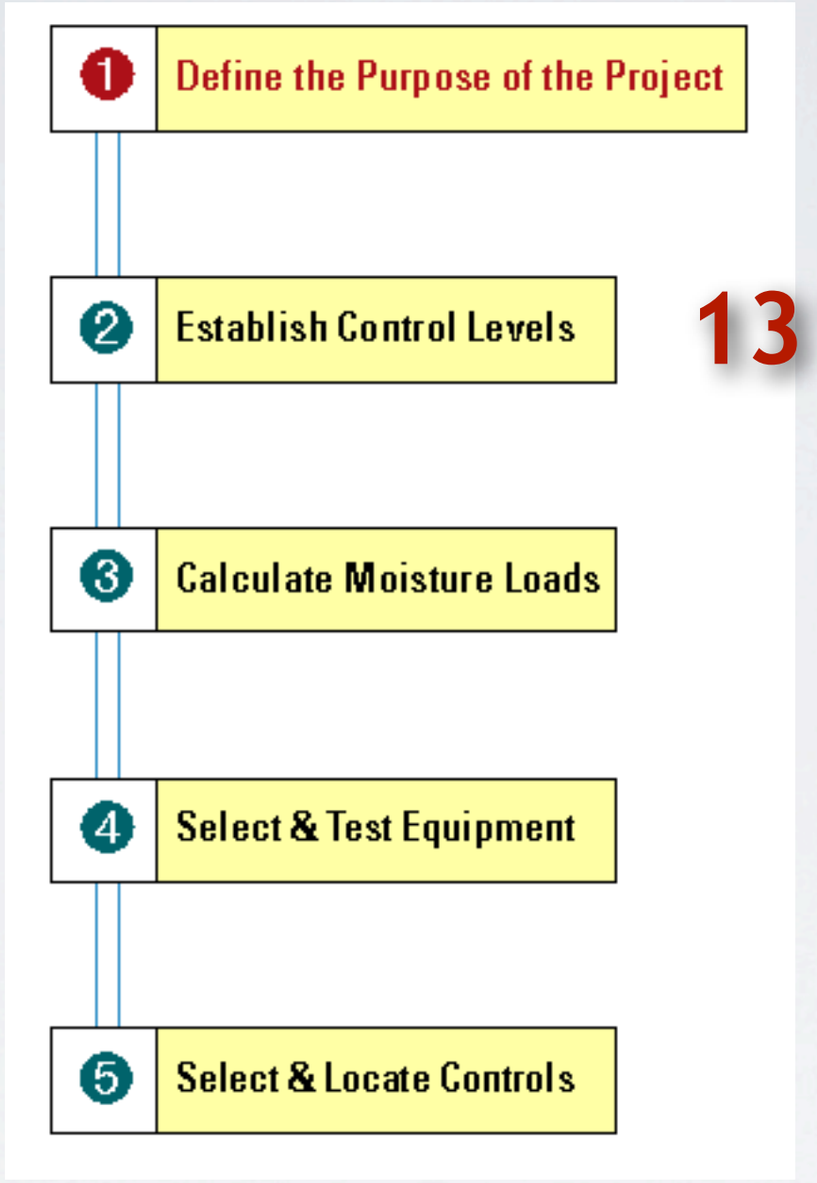
- Human comfort?
- Control everywhere?... or just in the pool area?
- Both high and low limits?
- Always? Usually? Only when rooms are occupied?

# Good definition of project purpose

**"Control the humidity in the hotel so that..."**

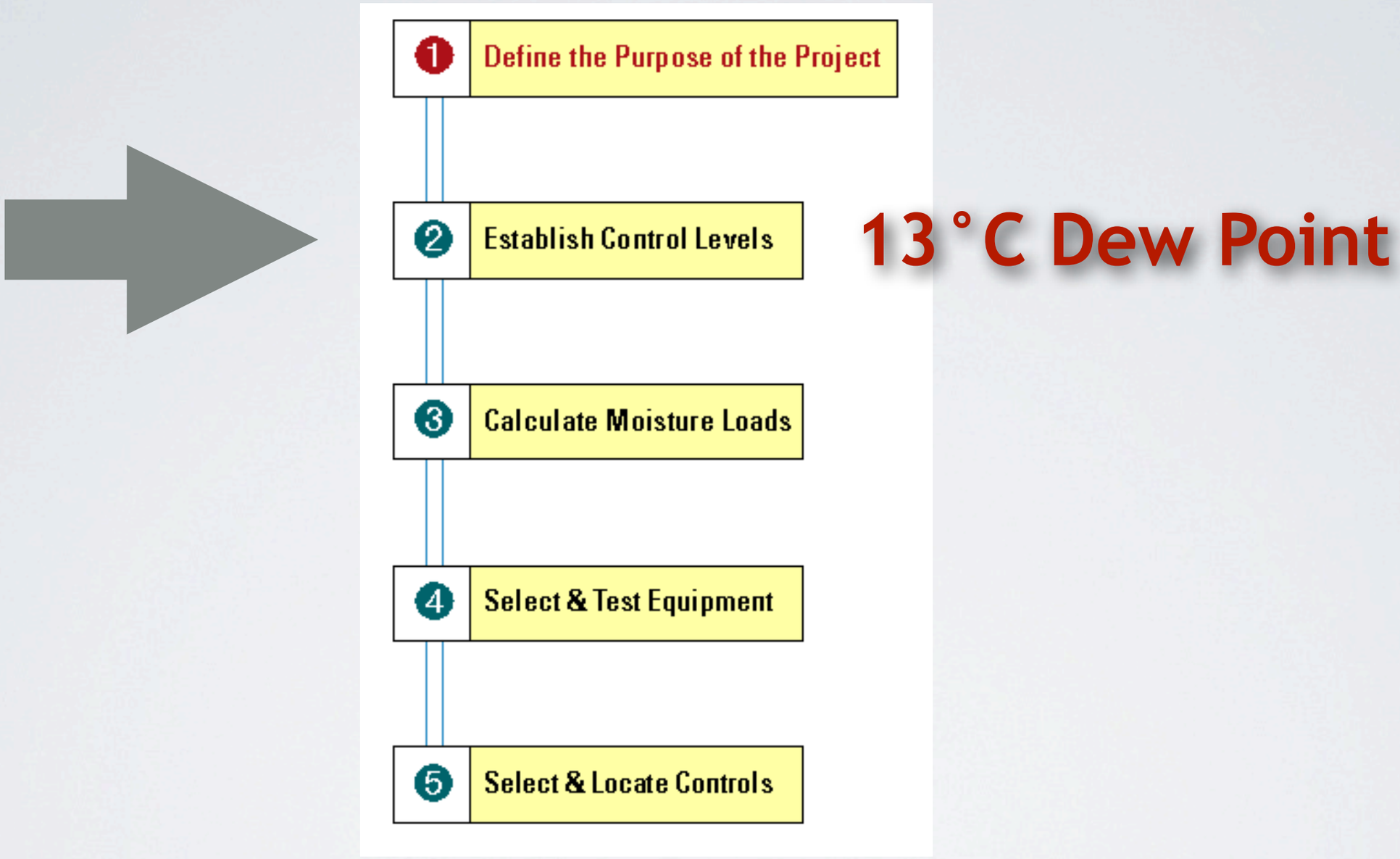
- Neither condensation nor high rh can occur in building cavities that would allow mold growth or other moisture damage to the building or its furnishings.
- Guest rooms, meeting rooms, dining rooms and offices are held within the ASHRAE comfort zones during both summer and winter seasons
- The system achieves these goals during all but 2% of the hours in a typical year.

# Step 2 - Establish control level that achieves purpose for humidity control



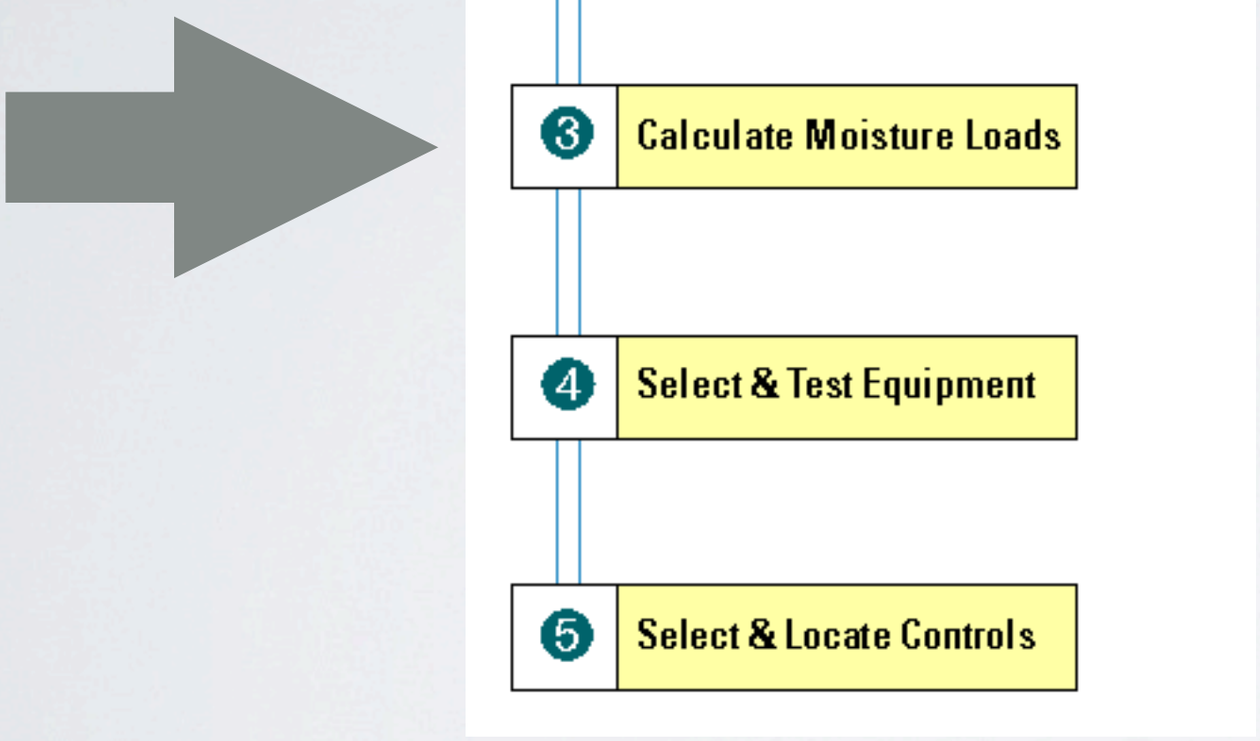

**13°C Dew Point**

# Step 2 - Establish control level that achieves purpose for humidity control




**13°C Dew Point**

# Step 3 - Calculate the humidity loads



# Step 3 - Calculate the humidity loads



1. Define the Purpose of the Project
2. Establish Control Levels
3. Calculate Moisture Loads
4. Select & Test Equipment
5. Select & Locate Controls

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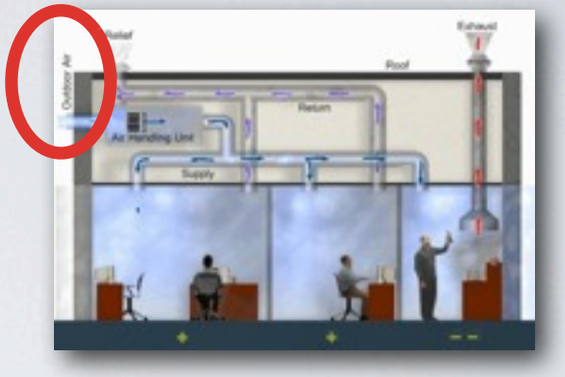

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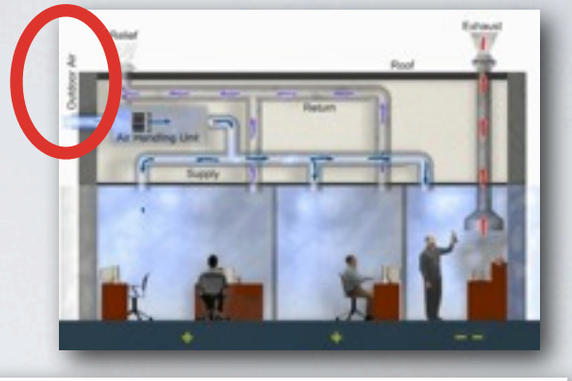


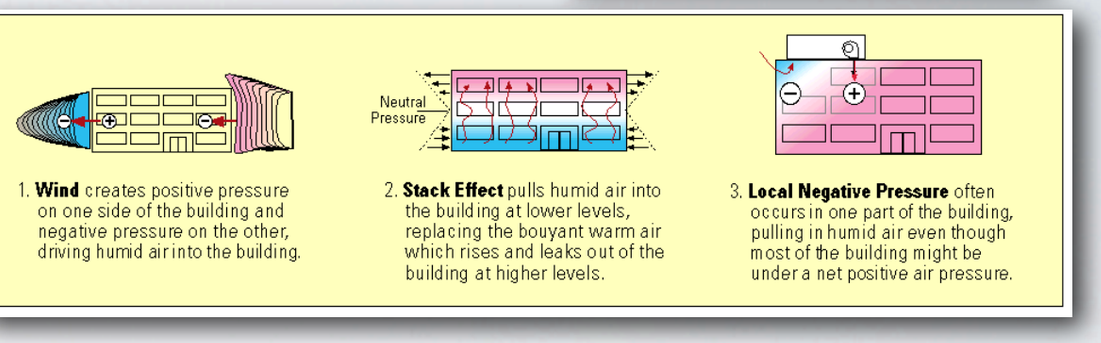


1. **Wind** creates positive pressure on one side of the building and negative pressure on the other, driving humid air into the building.
2. **Stack Effect** pulls humid air into the building at lower levels, replacing the bouyant warm air which rises and leaks out of the building at higher levels.
3. **Local Negative Pressure** often occurs in one part of the building, pulling in humid air even though most of the building might be under a net positive air pressure.

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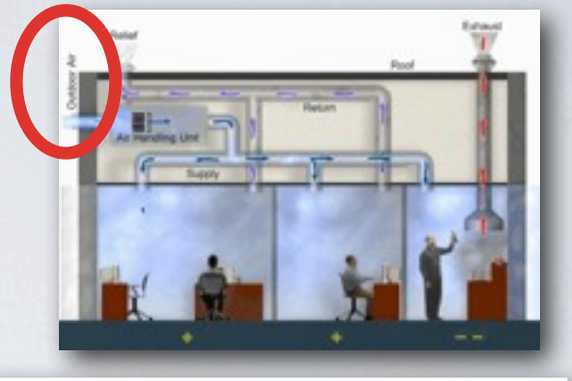


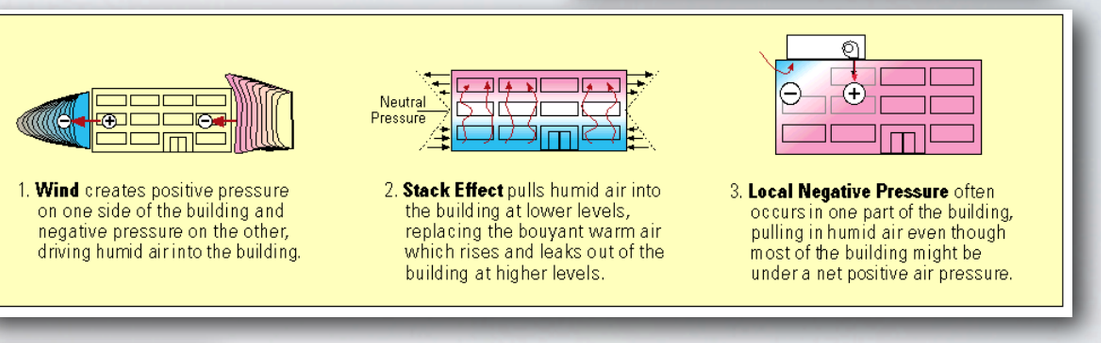


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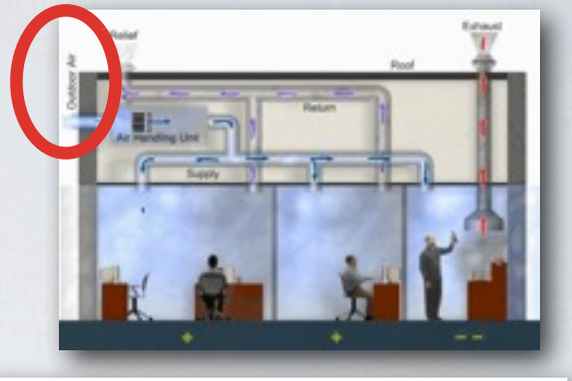


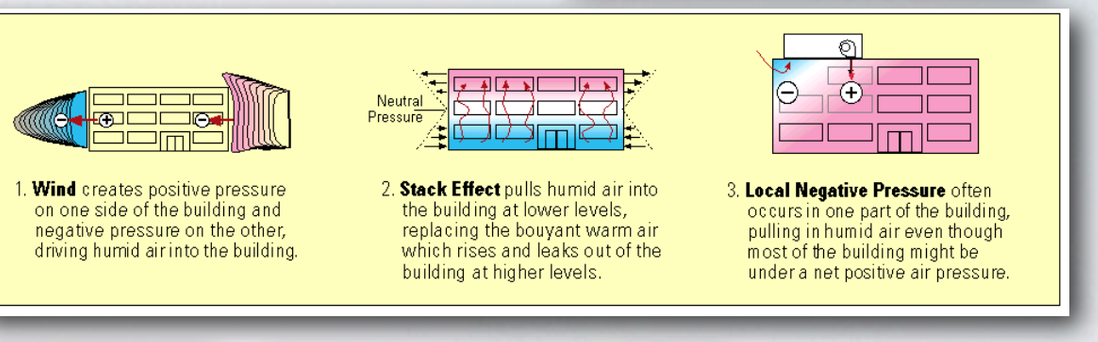




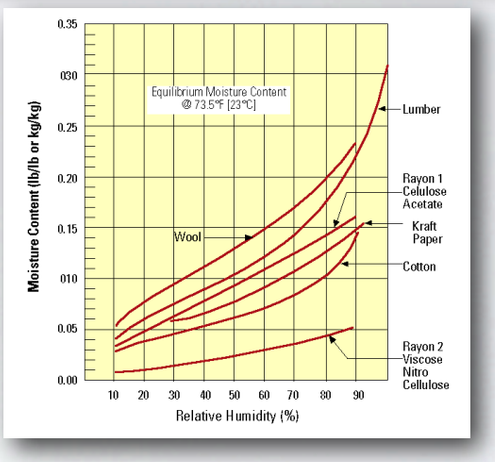

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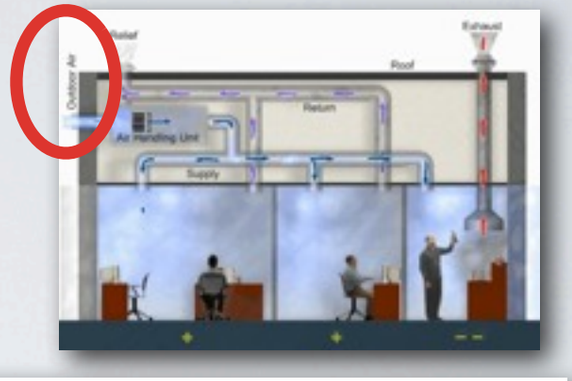
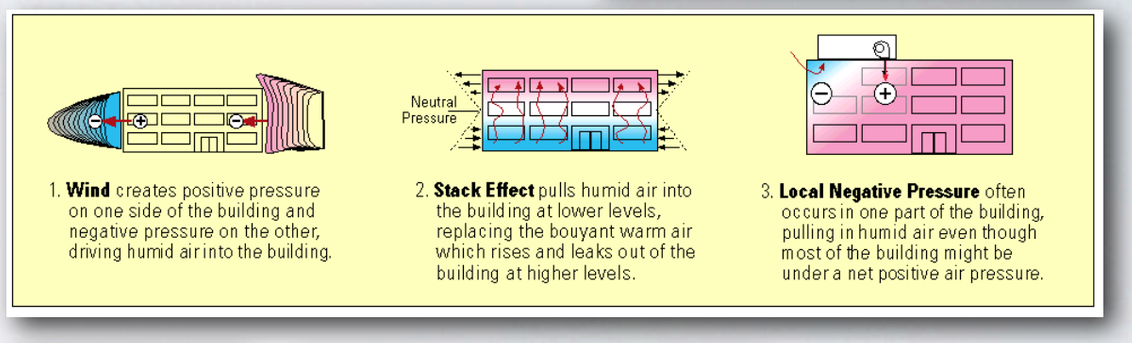
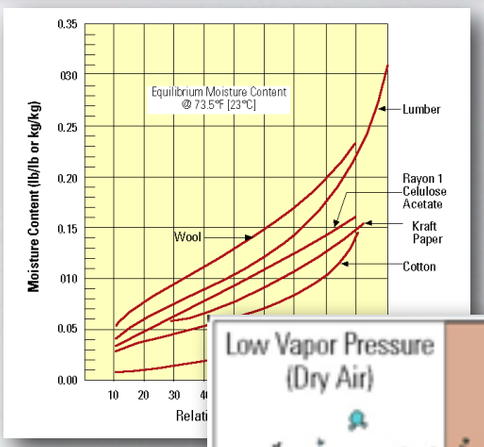
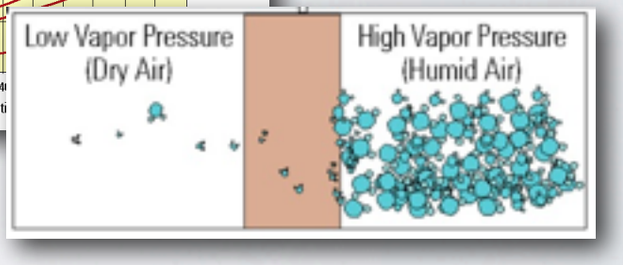


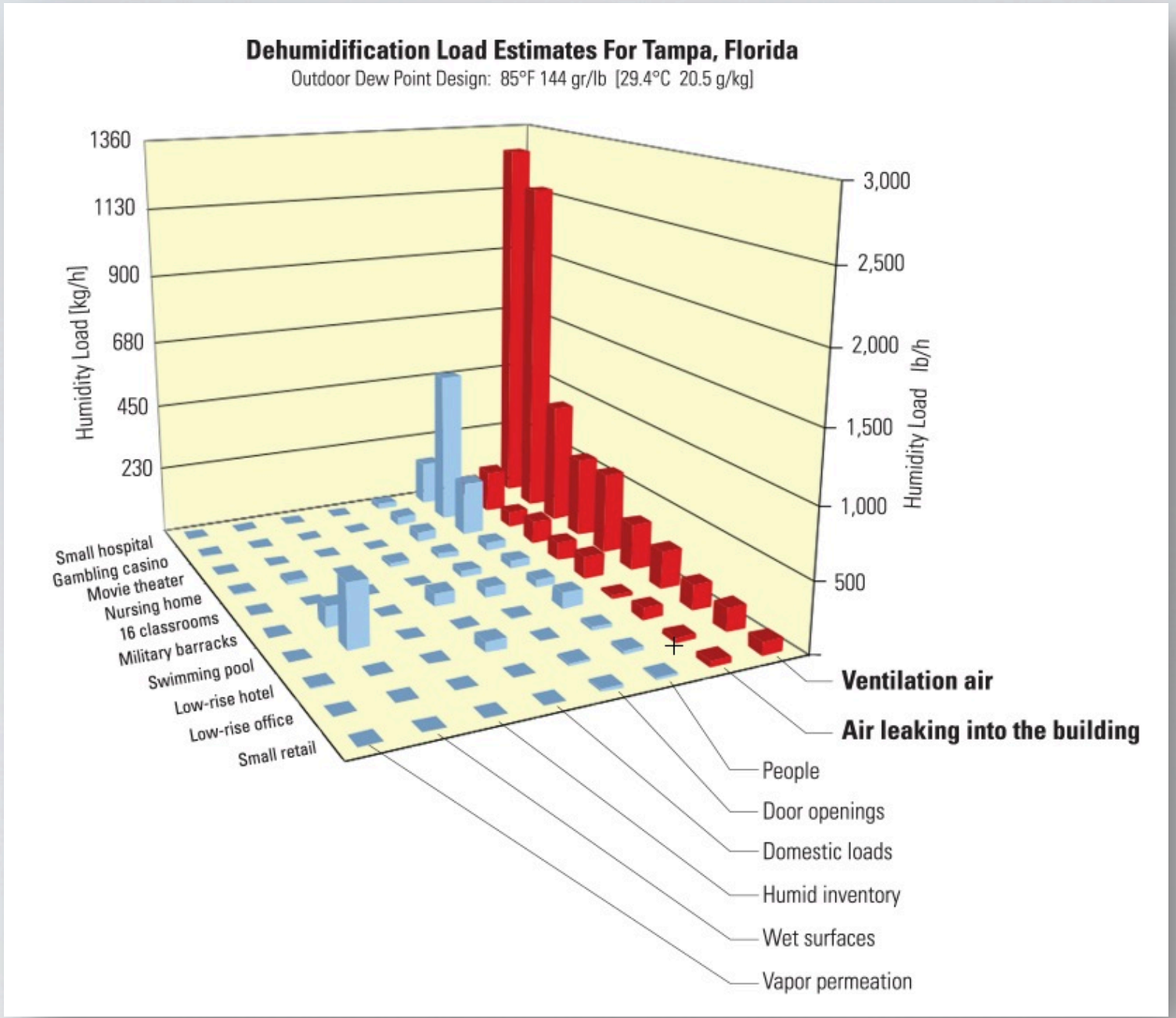





# Largest loads?
# Ventilation/makeup air and infiltration



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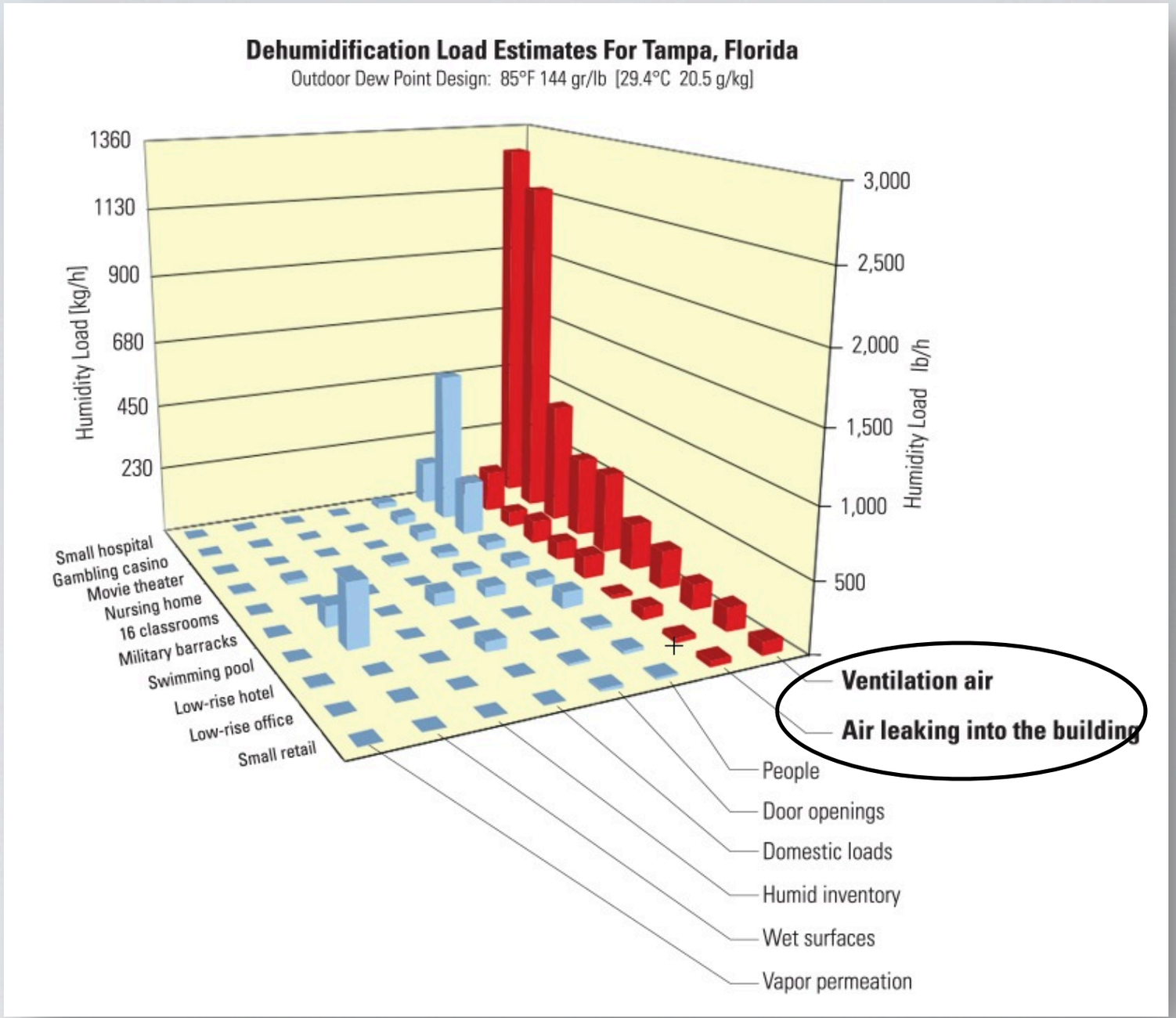
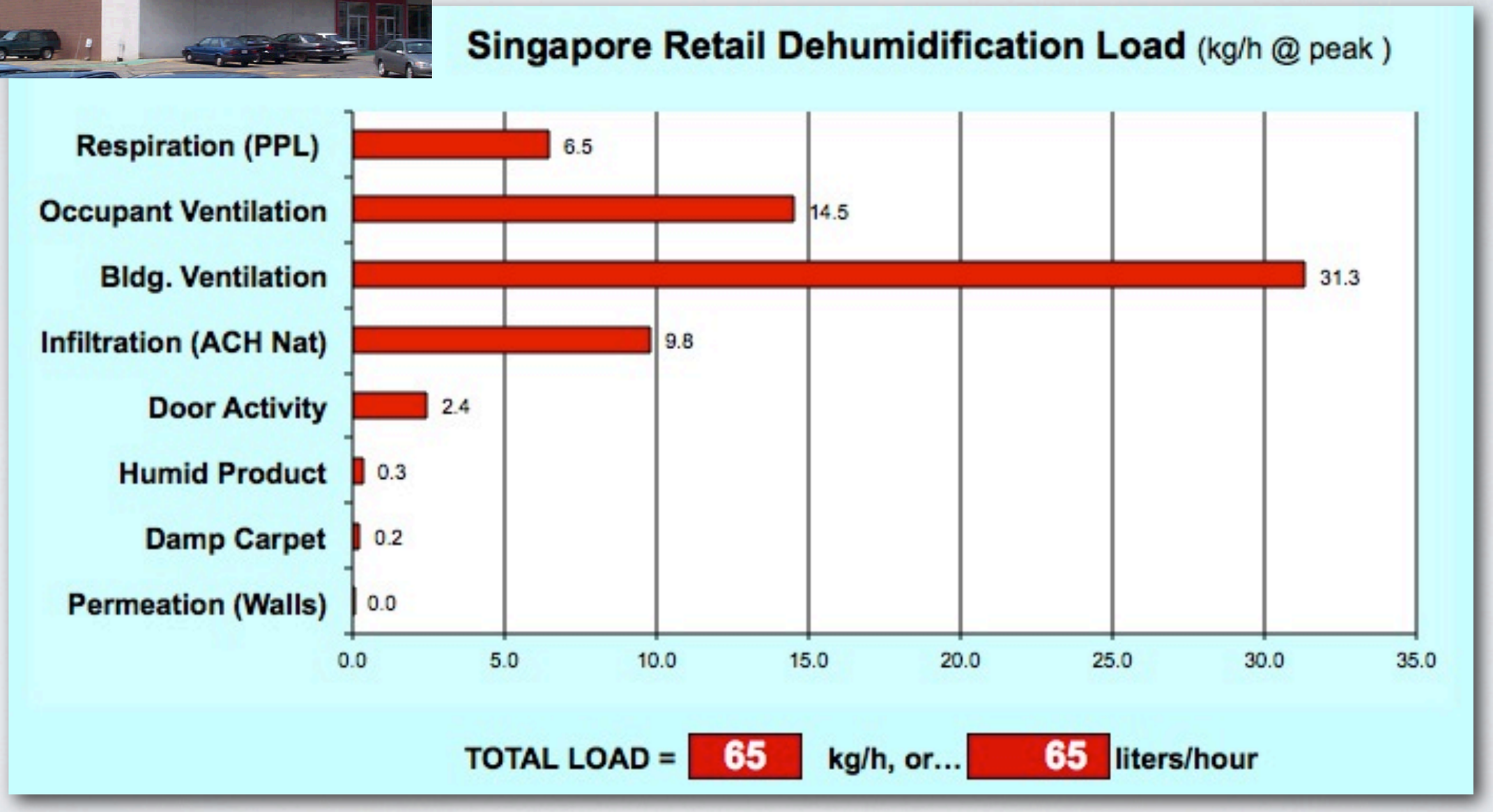


# Retail building in Singapore - Humidity load estimate



# Retail building in Singapore - Humidity load estimate




Ventilation to dilute contaminants from people

**Singapore Retail Dehu…ification Load** (kg/h @ peak )

| | |
|---|---|
| Respiration (PPL) | 6.5 |
| Occupant Ventilation | 14.5 |
| Bldg. Ventilation | 31.3 |
| Infiltration (ACH Nat) | 9.8 |
| Door Activity | 2.4 |
| Humid Product | 0.3 |
| Damp Carpet | 0.2 |
| Permeation (Walls) | 0.0 |

0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0

**TOTAL LOAD = 65 kg/h, or... 65 liters/hour**

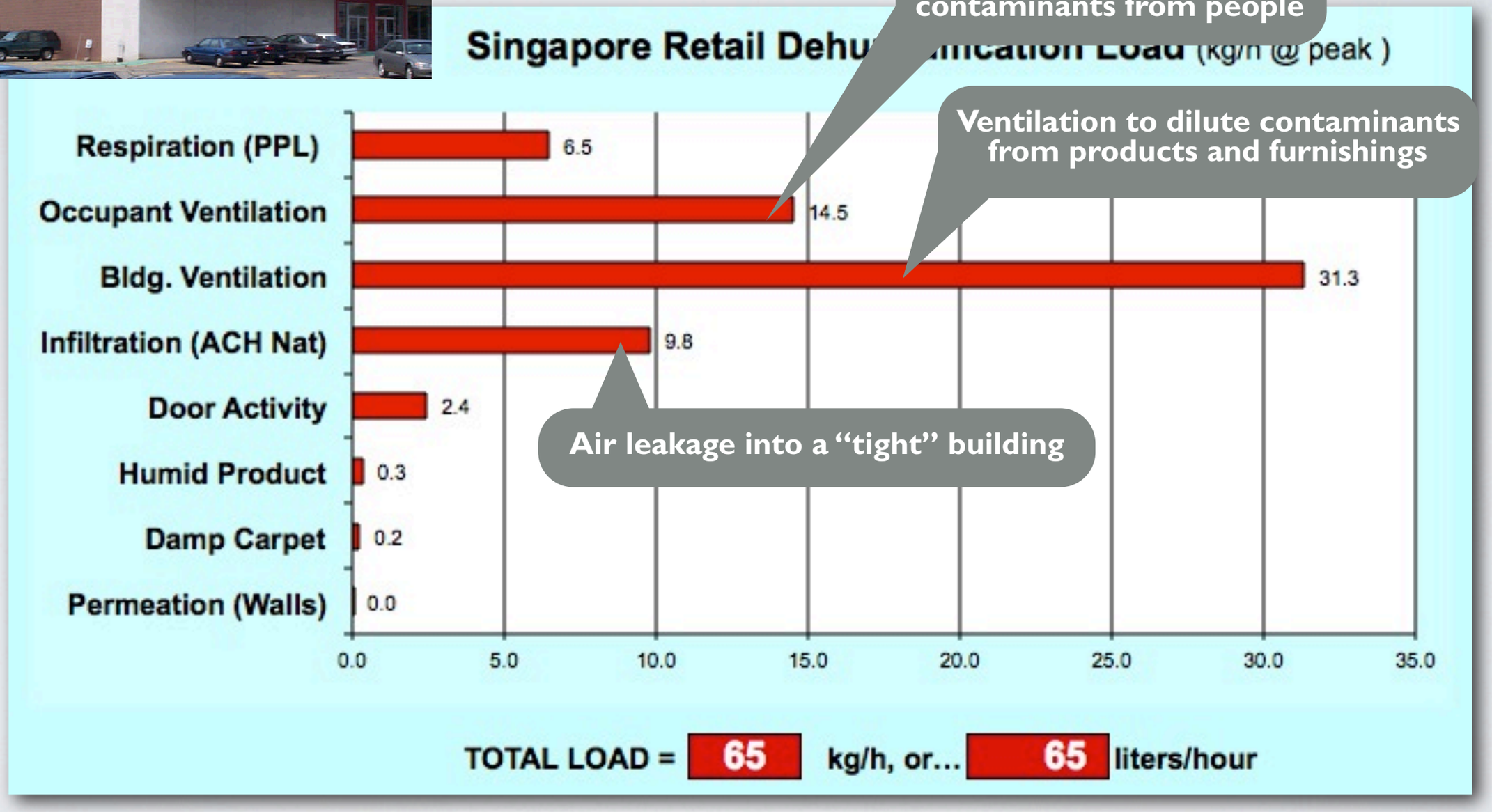
# Retail building in Singapore - Humidity load estimate






# Retail building in Singapore - Humidity load estimate



# Peak humidity loads - ASHRAE Research 1997
# Correcting 100 years of error - Now we know better

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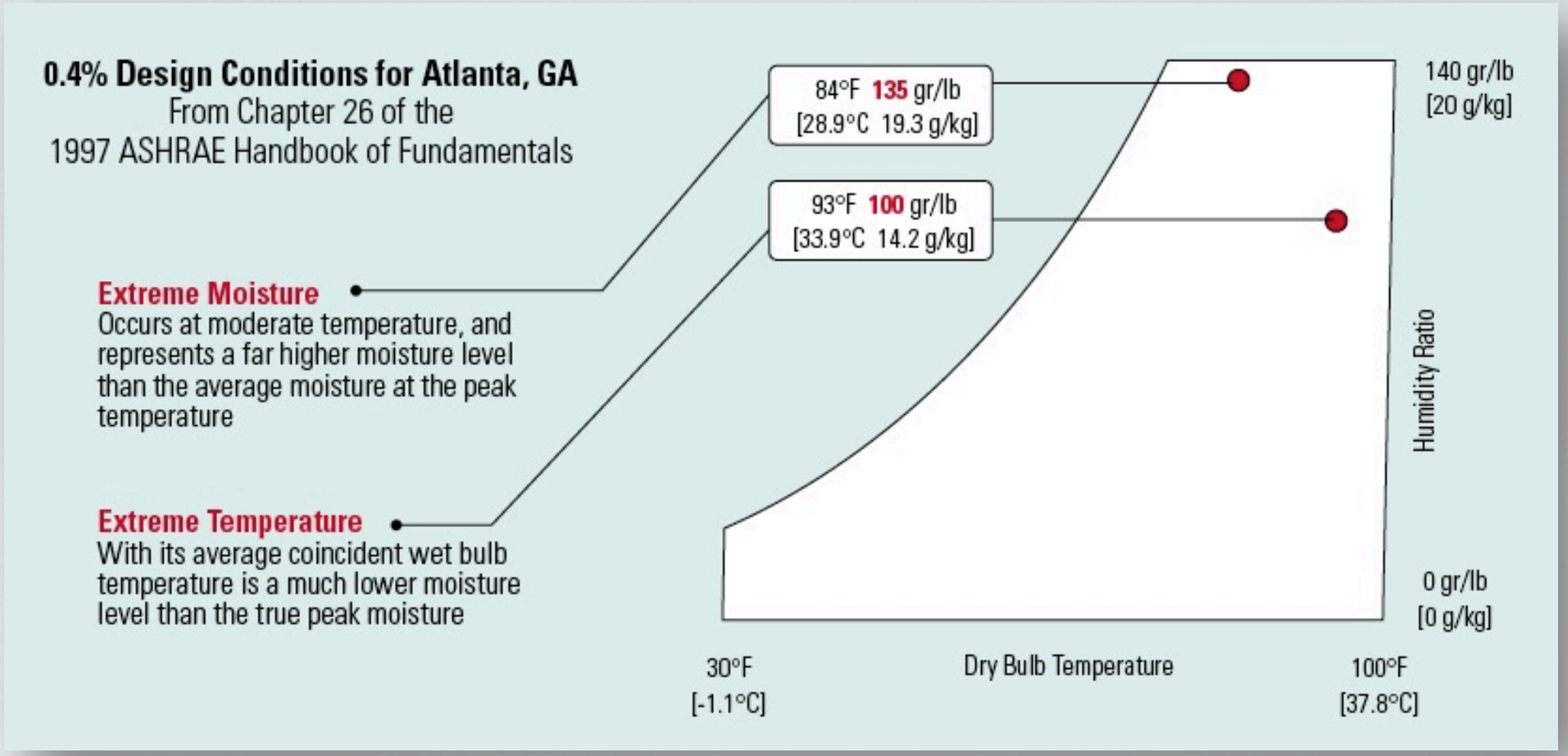
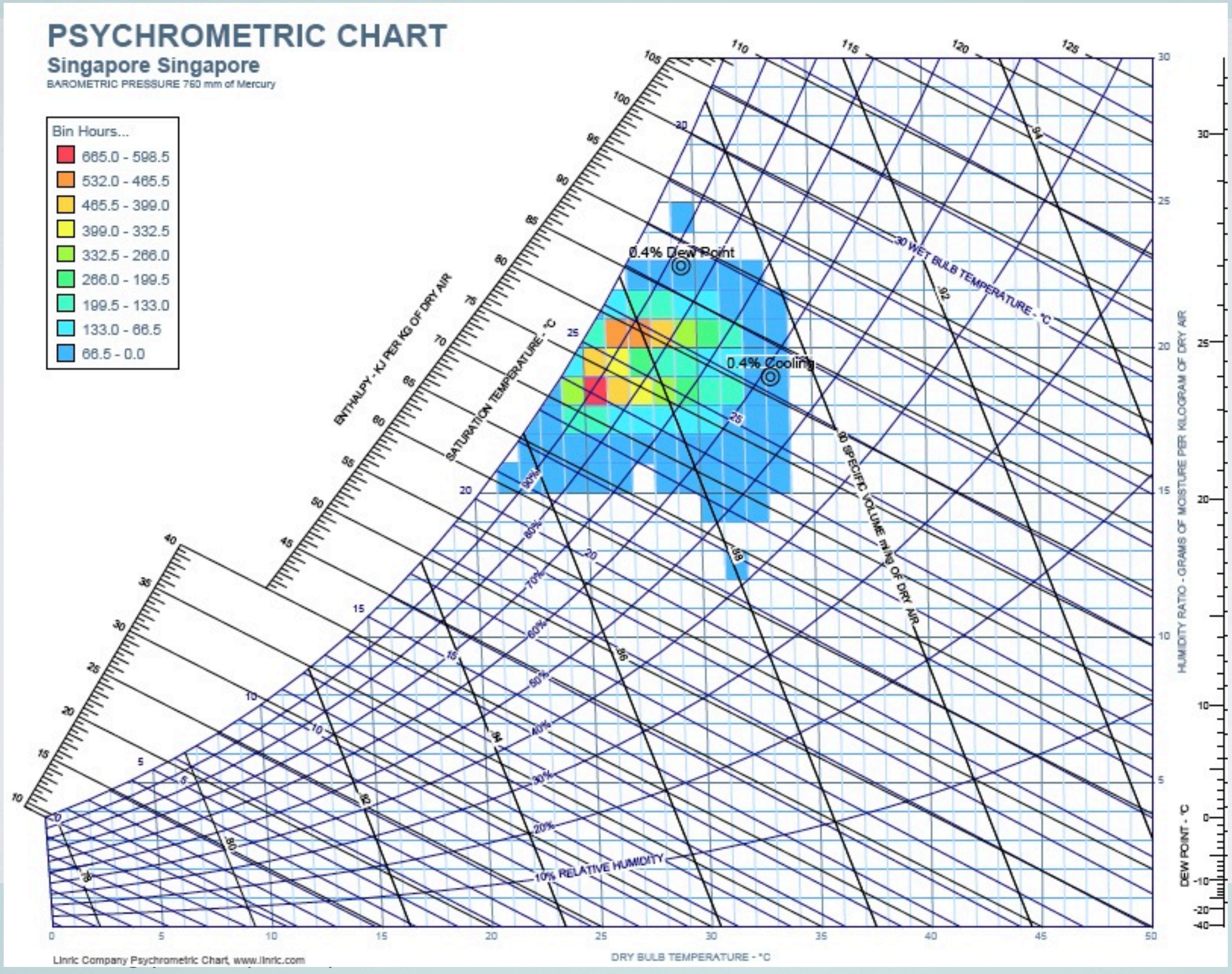


# ASHRAE Dew Point Design Values for Singapore



# How to find the peak design dew point?
# ASHRAE Fundamentals - 1997 or later

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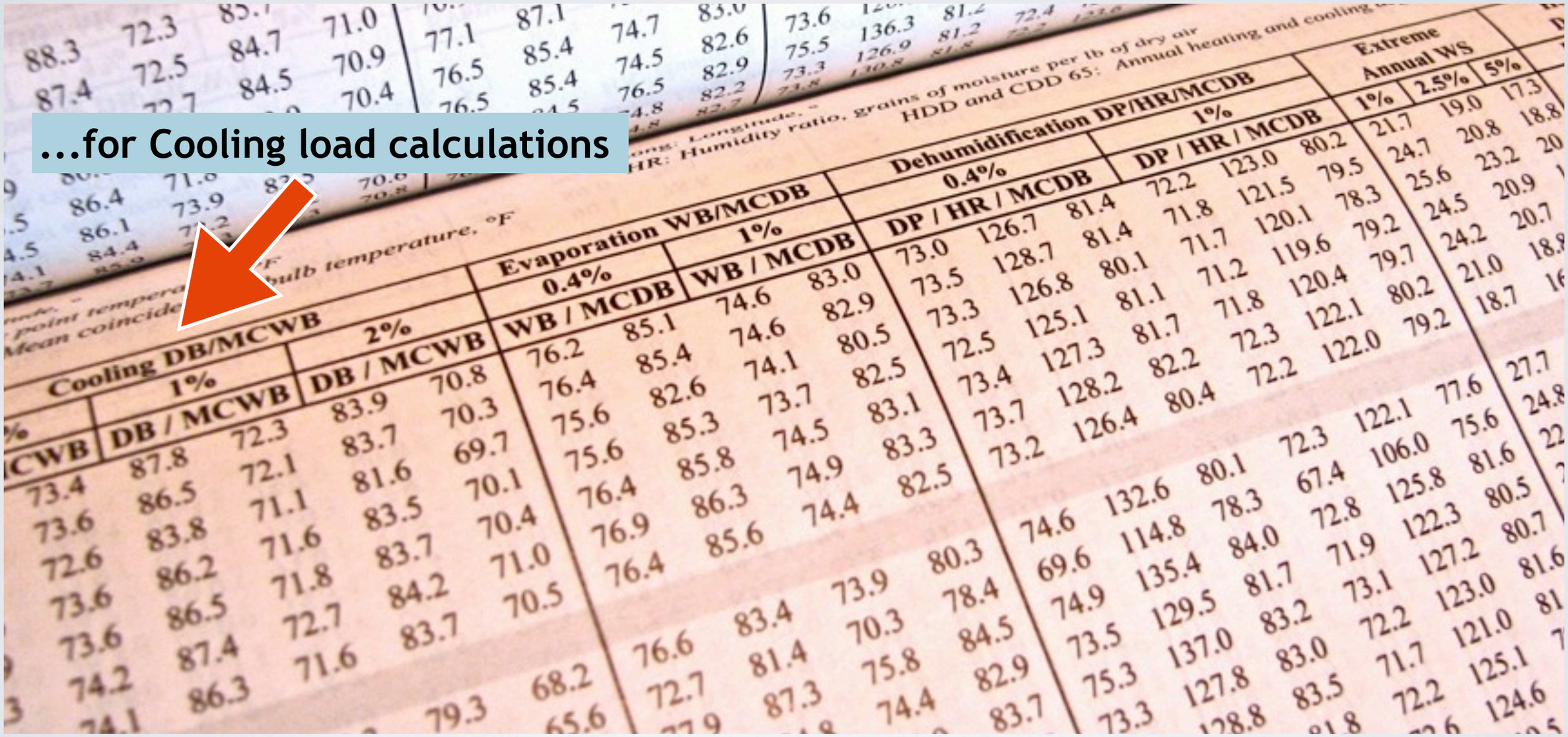
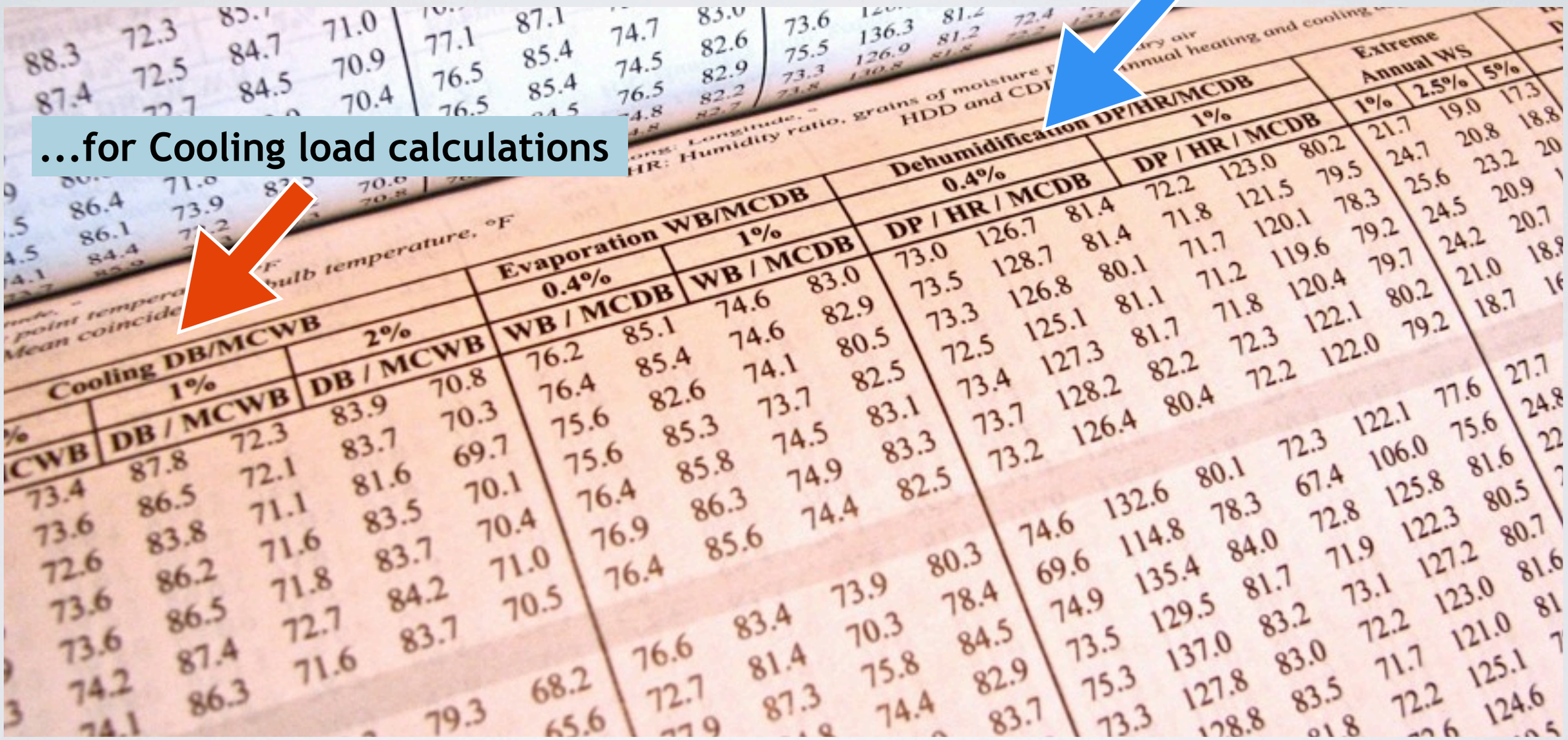


# How to find the peak design dew point?
# ASHRAE Fundamentals - 1997 or later

**...for dehumidification load calculations, and DOAS system design**

**...for Cooling load calculations**



# Singapore - ASHRAE peak humidity design conditions

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| 0.4% Dry Bulb |
| --- |
| **33.2°** DB<br>26.3° MCWB |
| 19.0 g/kg |

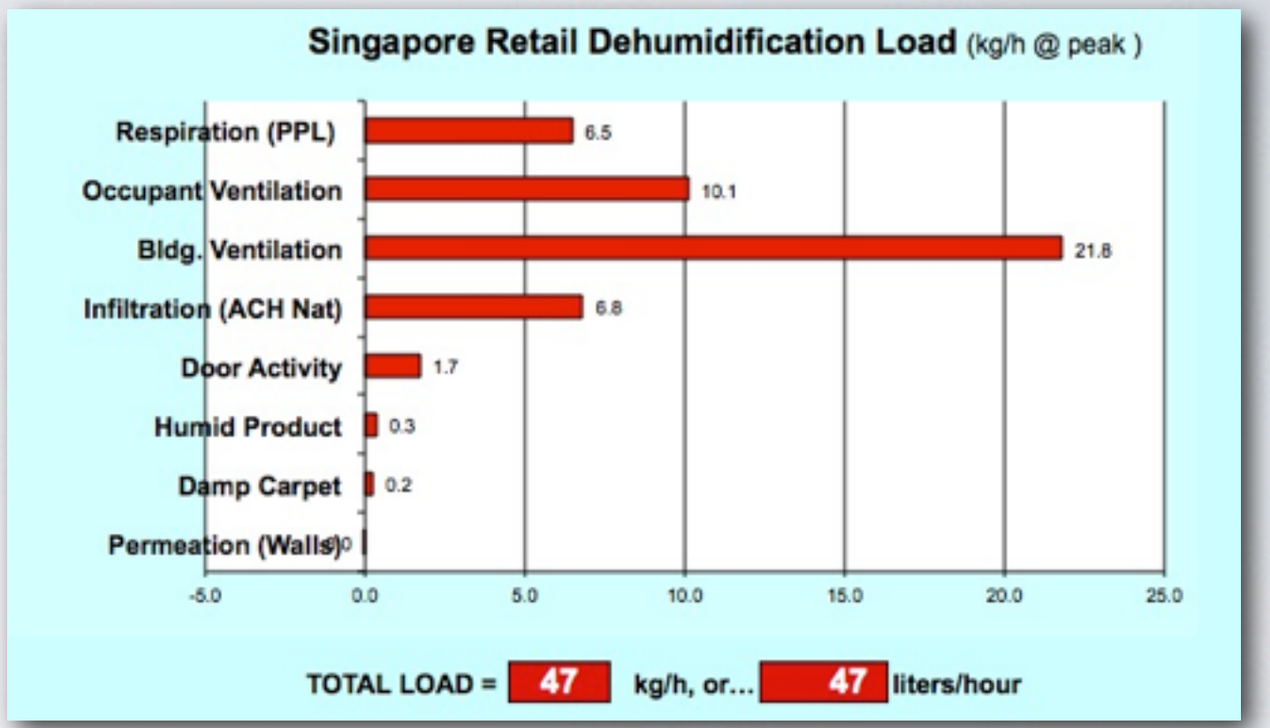
# Singapore - ASHRAE peak humidity design conditions

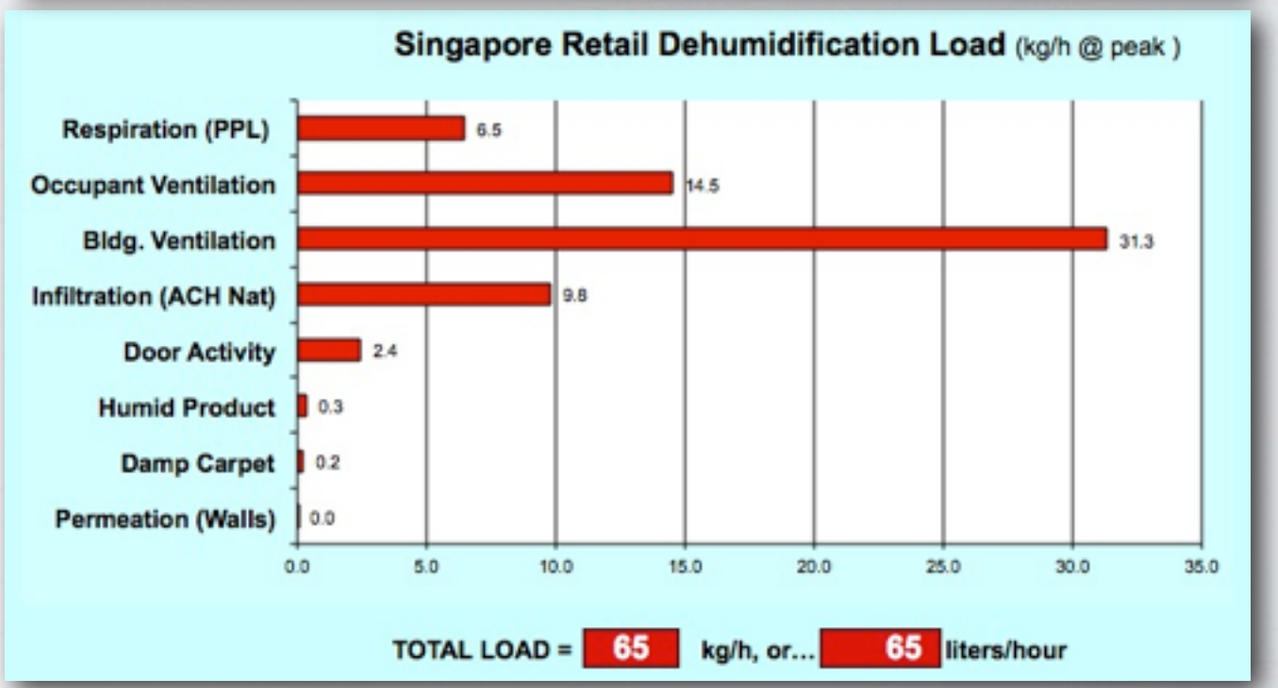
| 0.4% Dry Bulb | 0.4% Dew Point |
|---|---|
| **33.2°** DB<br>26.3° MCWB | **29.4°**DB<br>27.6°MCWB |
| 19.0 g/kg | 22.8 g/kg |

# Singapore - ASHRAE peak humidity design conditions

| 0.4% Dry Bulb | 0.4% Dew Point | **Difference at peak dew point** |
|---|---|---|
| **33.2°** DB<br>26.3° MCWB | **29.4°**DB<br>27.6°MCWB | **-3.8°C DB** |
| 19.0 g/kg | 22.8 g/kg | **+3.8 g/kg** |

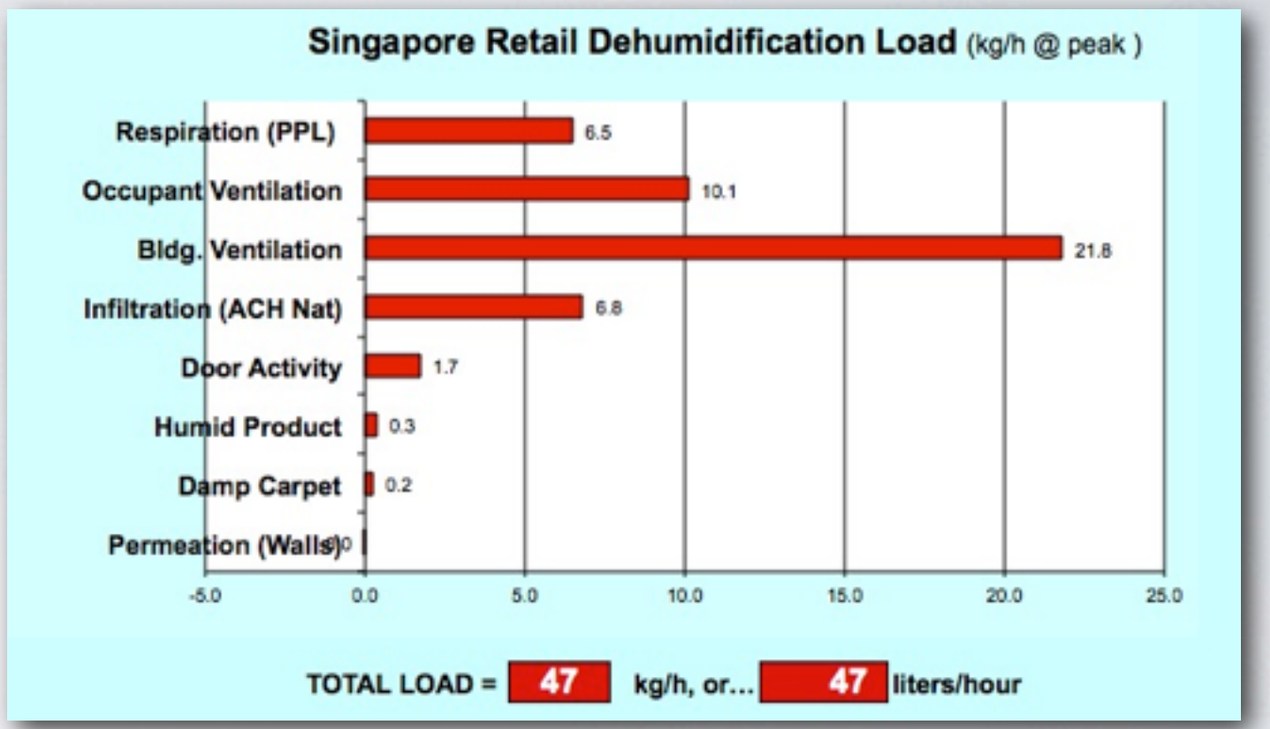
# load at peak dry bulb vs. peak dew point

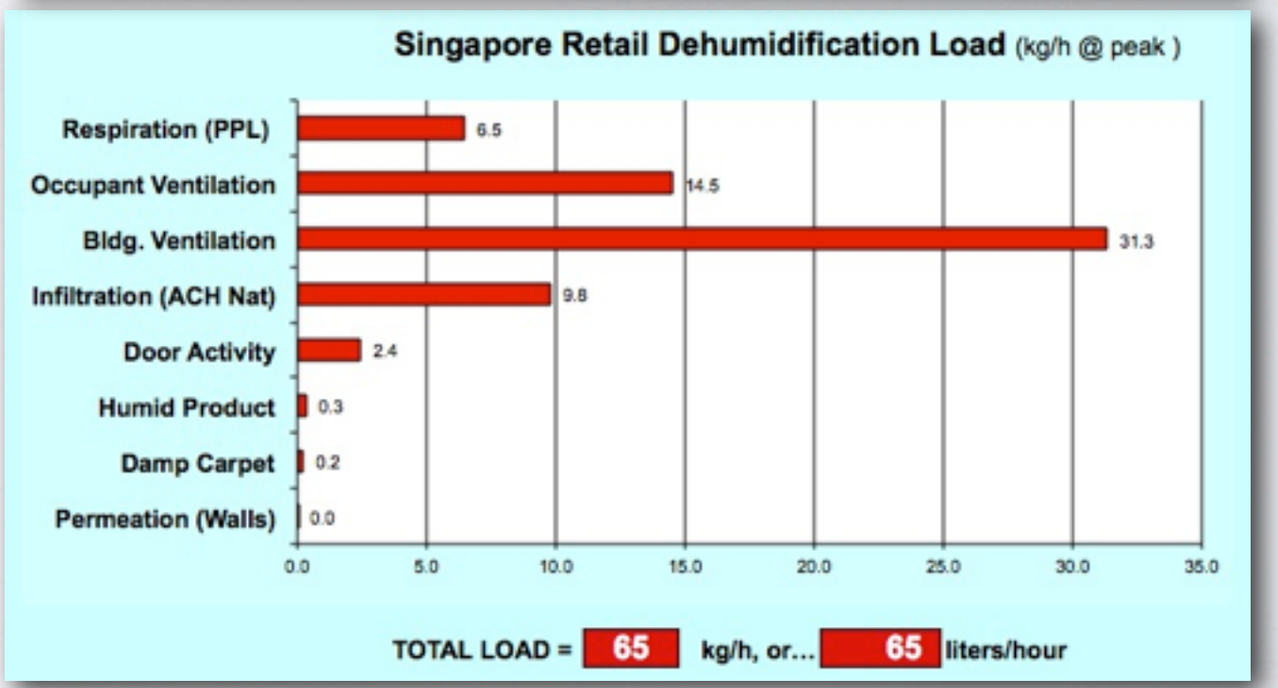


# load at peak dry bulb vs. peak dew point

**47** kg/h at peak Dry Bulb



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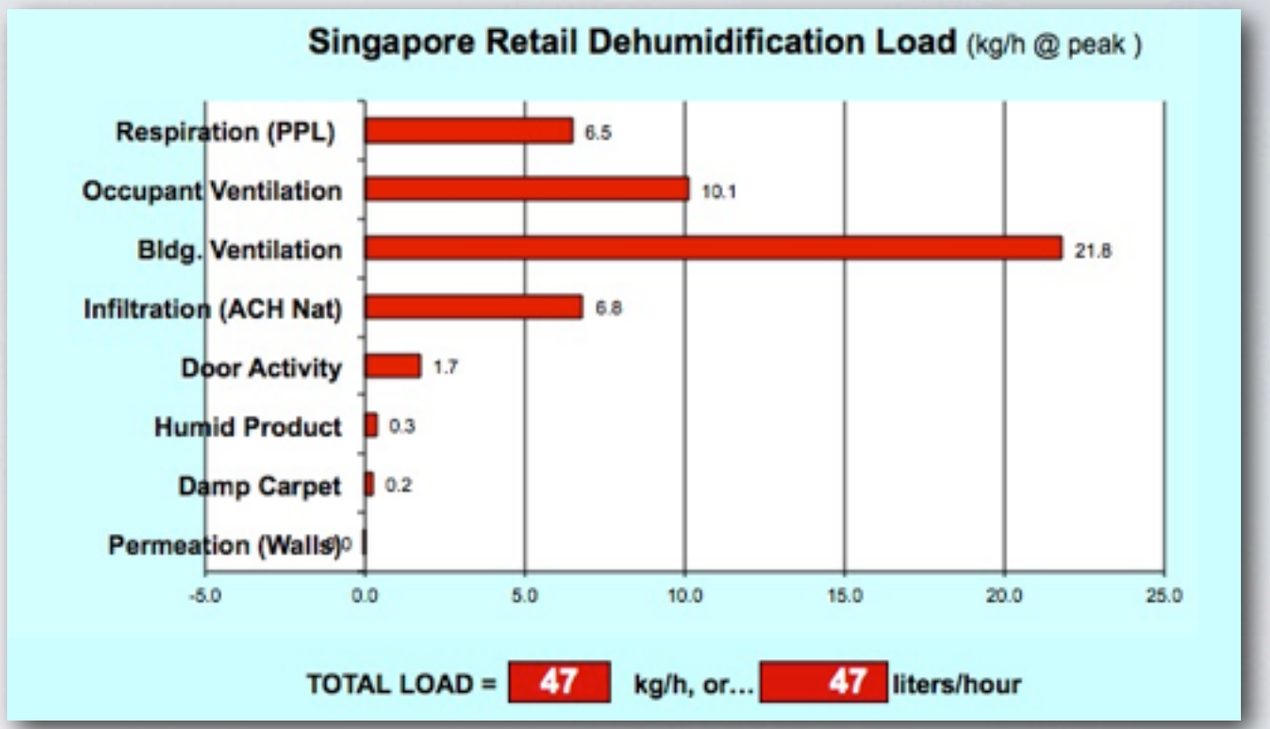
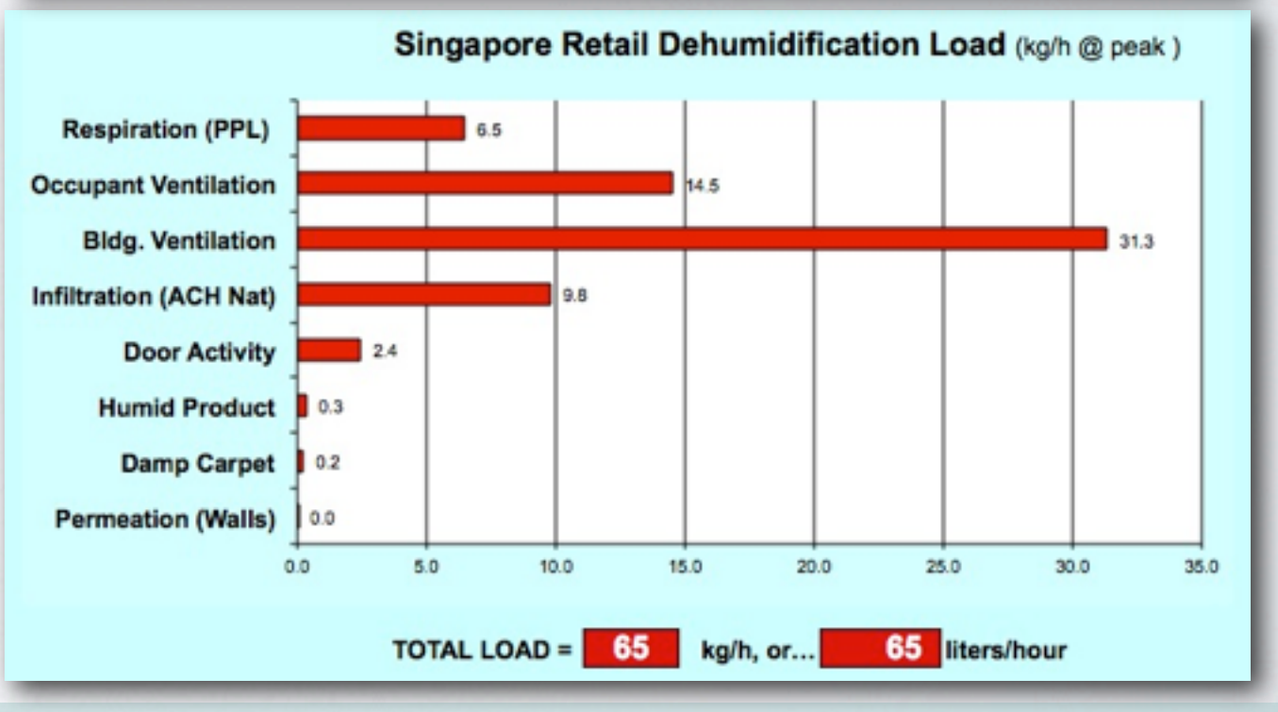
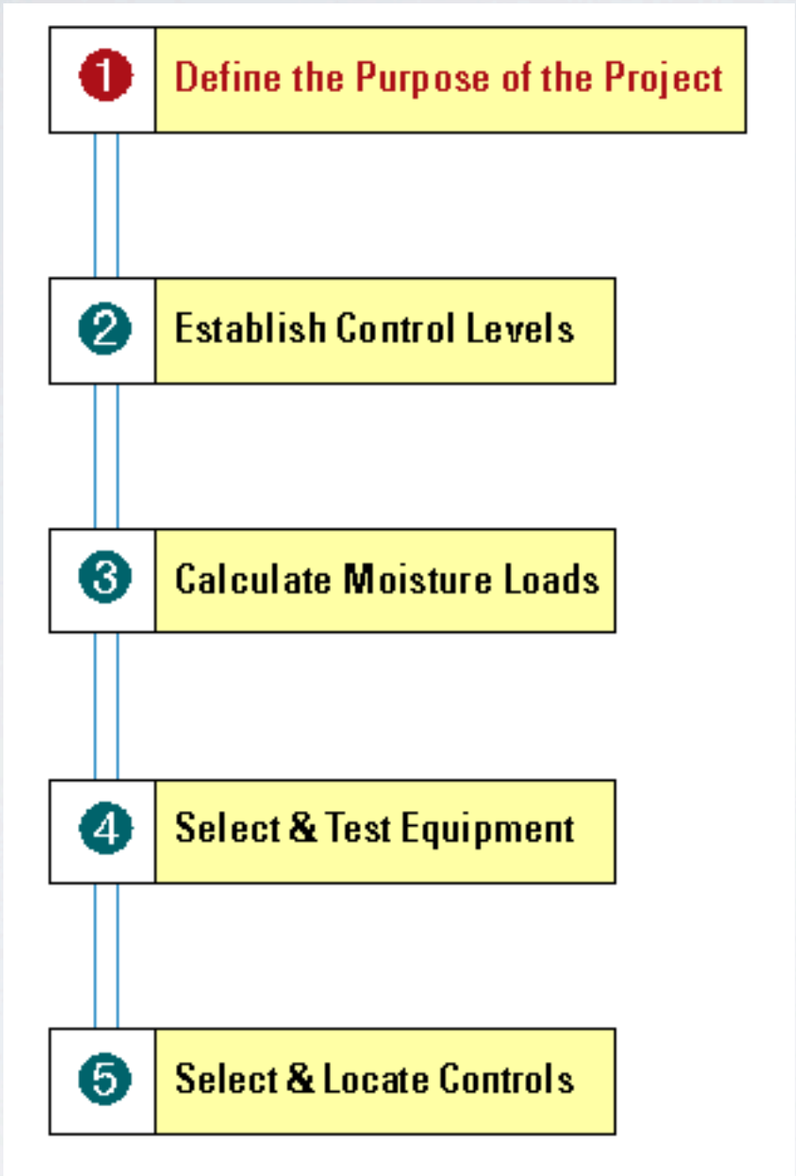



**65** kg/h at peak Dew Point



# Step 4 - Size and select the dehumidifier



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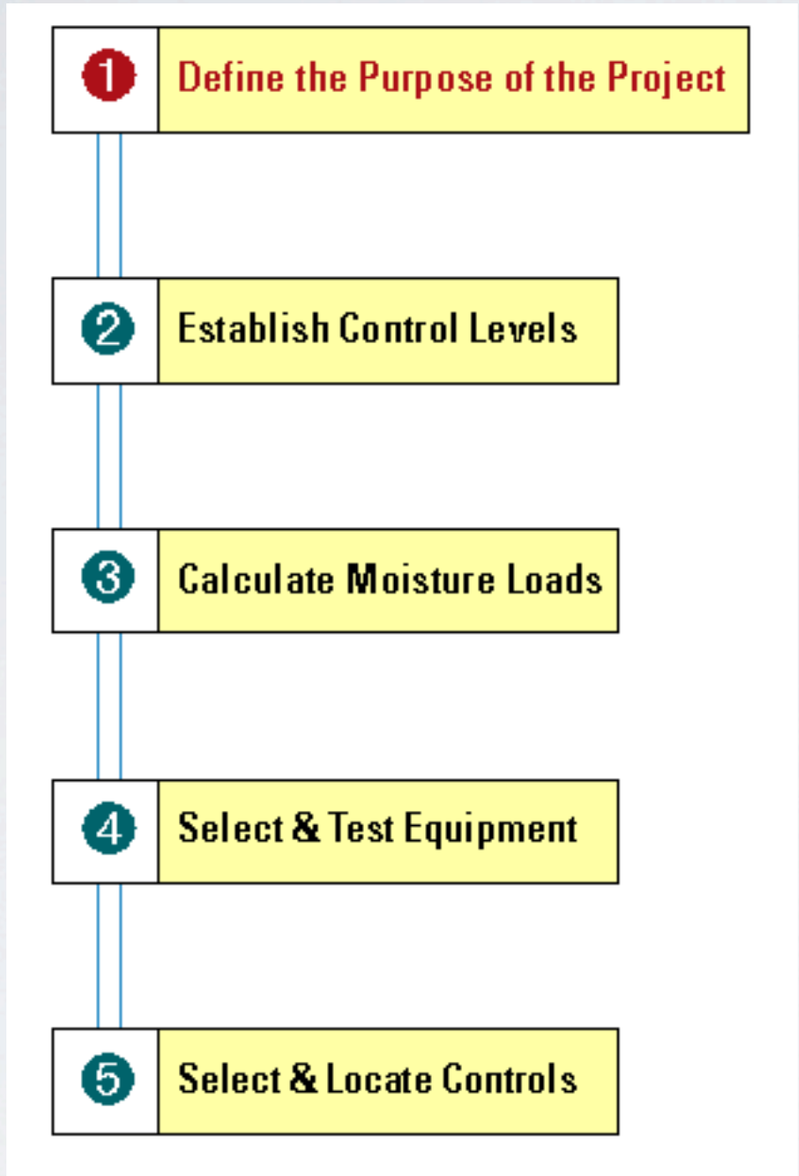
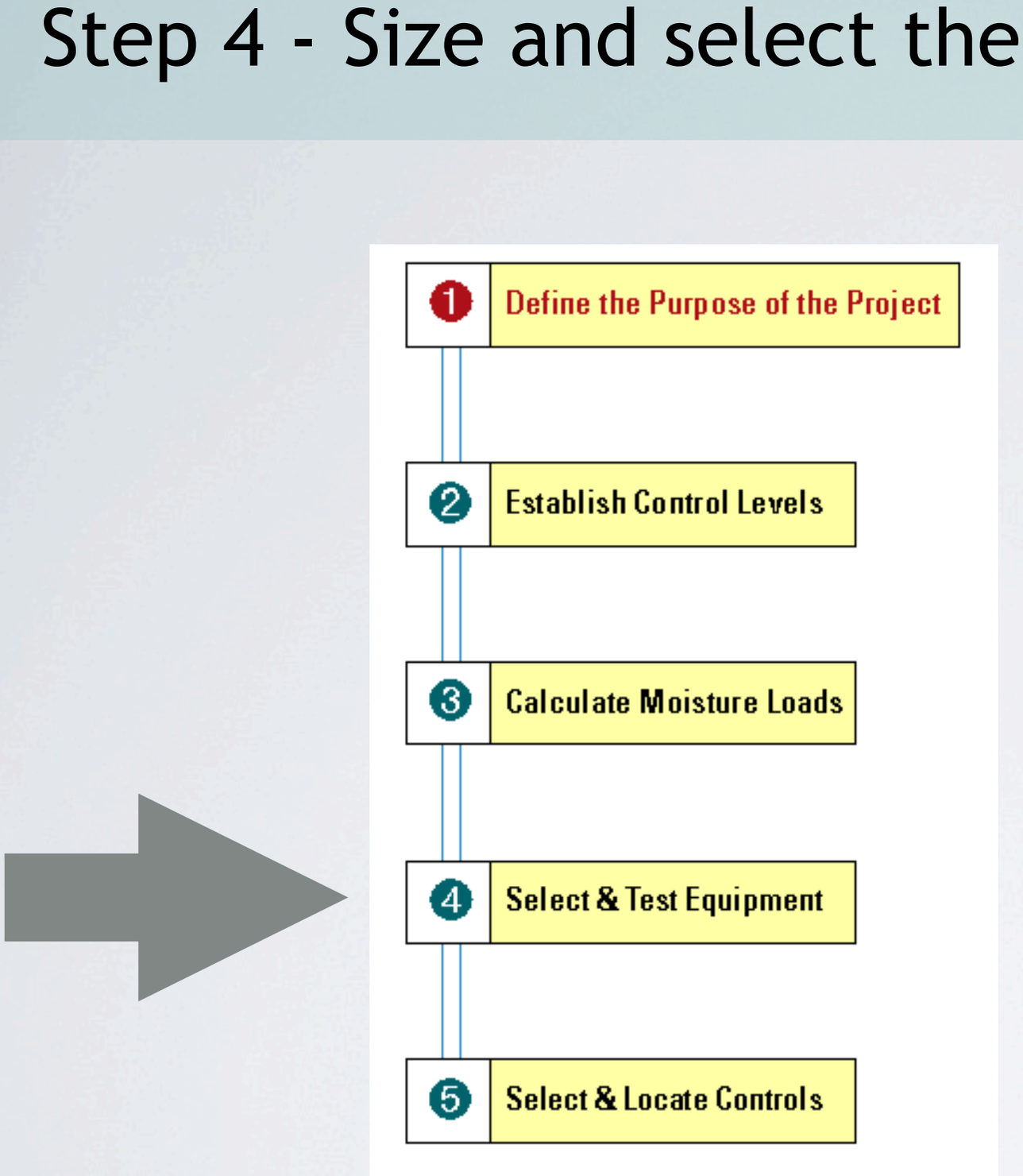



## Cool-Reheat Dehumidifier



# Step 4 - Size and select the dehumidifier



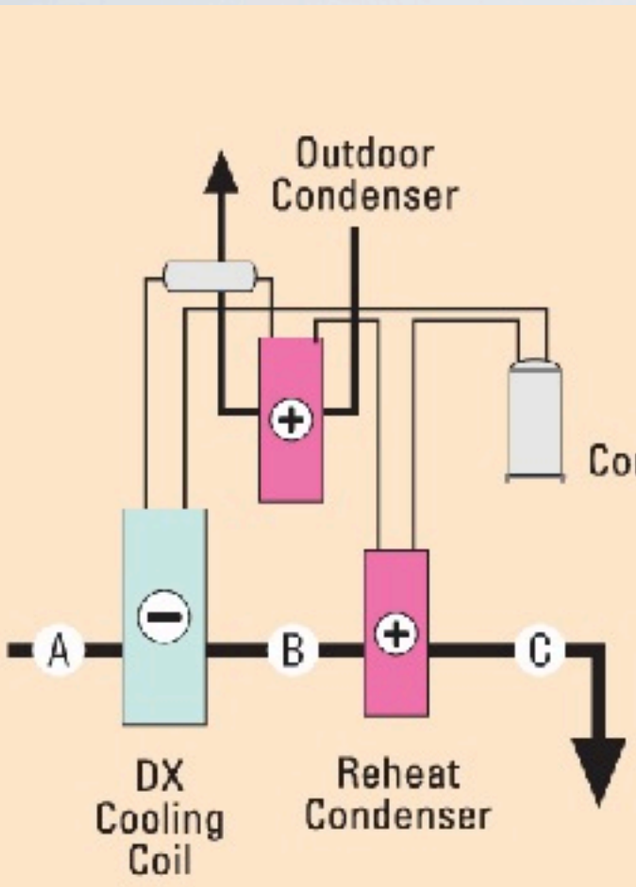

## Cool-Reheat Dehumidifier



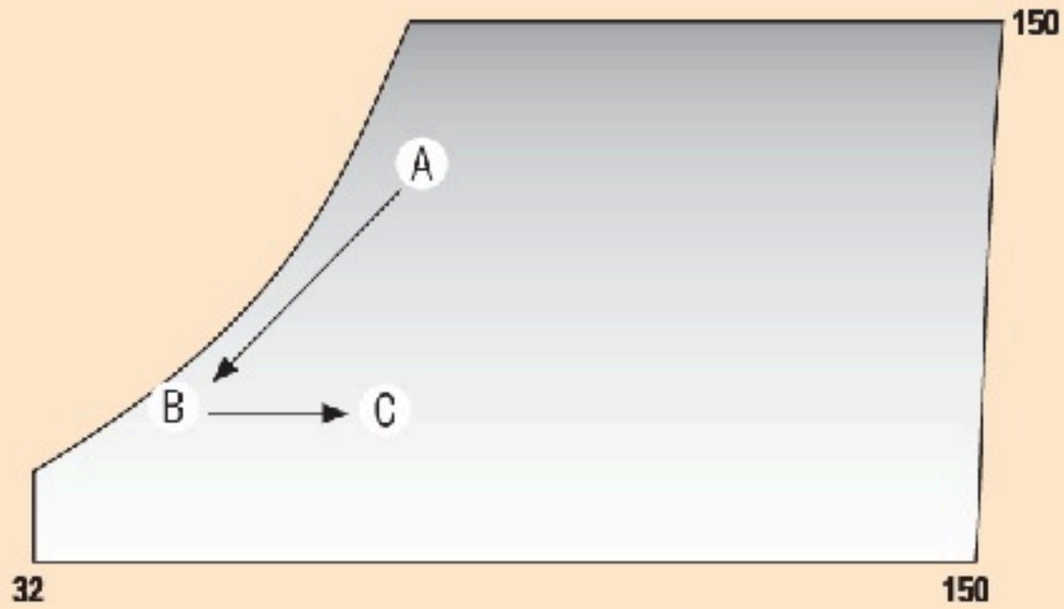
## Desiccant Dehumidifier



# Cool-Reheat Dehumidifier

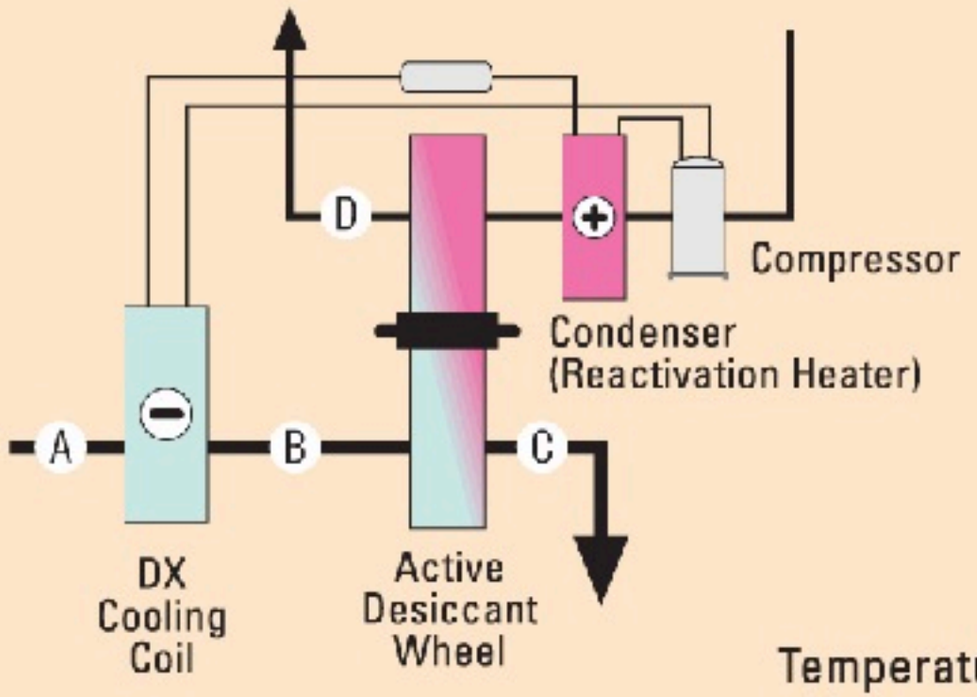



**Mechanical Dehumidifier Using Condenser Reheat**

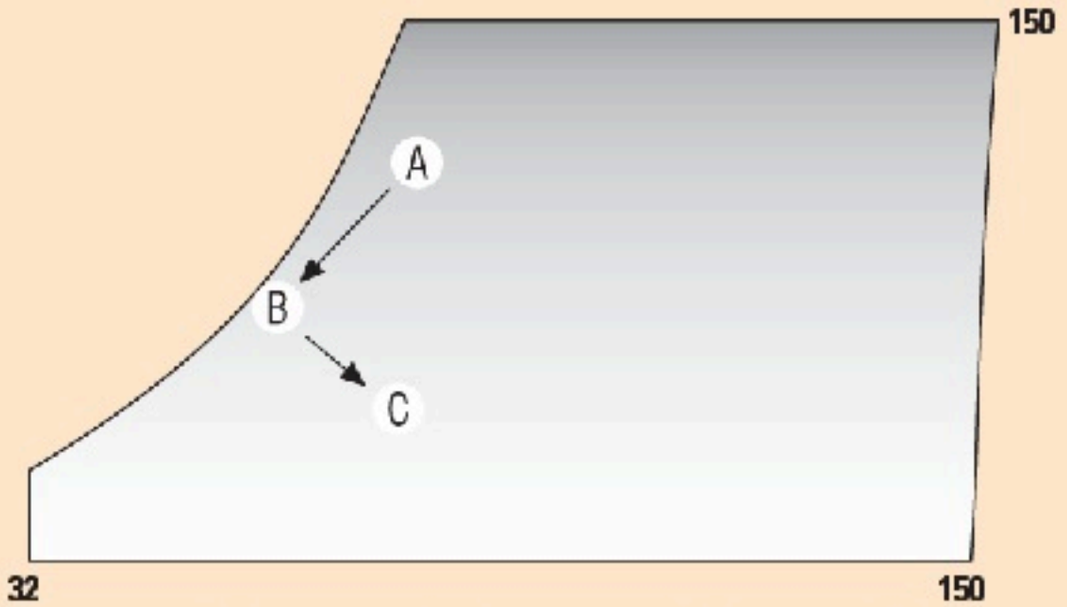



| | A | B | C |
|---|---|---|---|
| Temperature (°F) | 80 | 50 | 75 |
| Moisture (gr/lb) | 124 | 54 | 54 |
| Air Flow (scfm) | 2,000 | 2,000 | 2,000 |
| (°C) | 26.7 | 10.0 | 23.9 |
| (g/kg) | 17.7 | 7.7 | 7.7 |
| (l/s) | 942 | 942 | 942 |

# Desiccant Dehumidifier




**Desiccant Dehumidifier**
**Using Condenser Heat Reactivation**




| | A | B | C | D |
|---|---|---|---|---|
| Temperature (°F) | 80 | 60 | 77 | 98 |
| Moisture (gr/lb) | 124 | 77 | 54 | 144 |
| Air Flow (scfm) | 2,000 | 2,000 | 2,000 | 2,000 |
| (°C) | 26.7 | 16.0 | 25.0 | 37.0 |
| (g/kg) | 17.7 | 11.0 | 7.7 | 20.6 |
| (l/s) | 942 | 942 | 942 | 942 |

# Measuring Dehumidification

How to measure?

**Humidity ratios (gr/lb or g/kg) before and after the dehumidifier**

# Measuring Dehumidification



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# Measuring Dehumidification



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# Measuring Dehumidification



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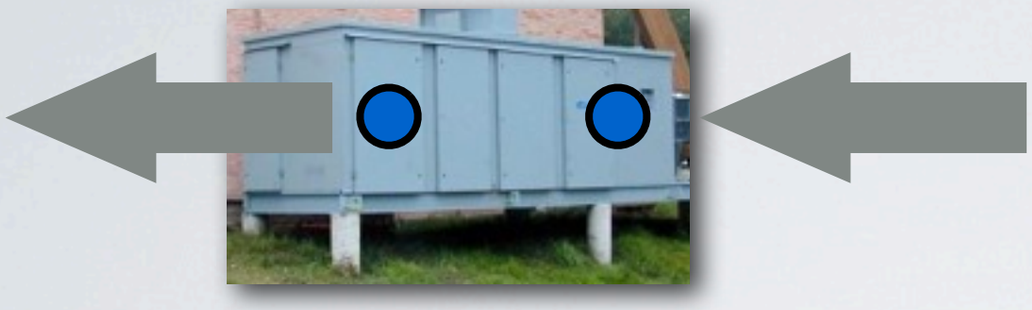

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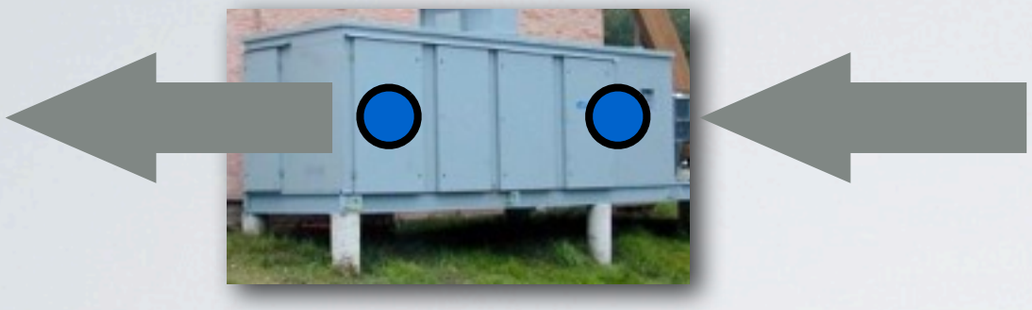

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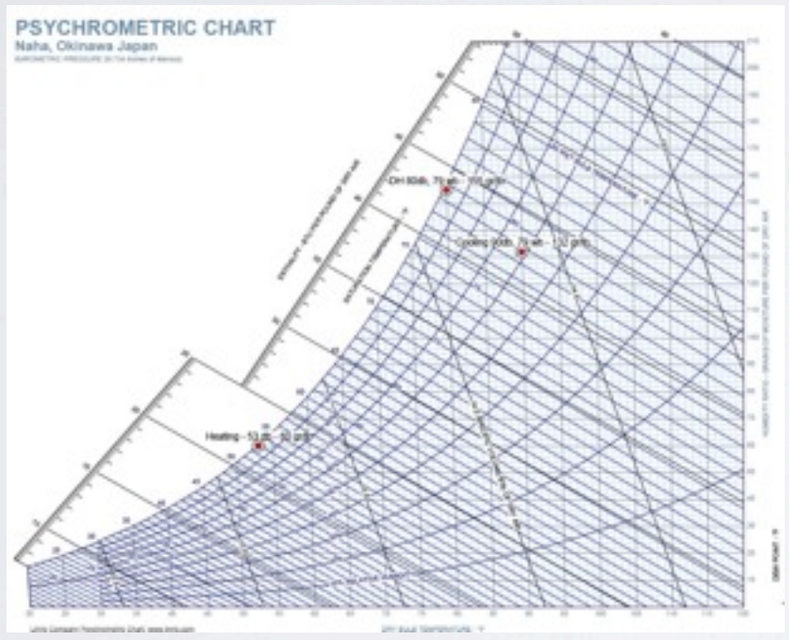

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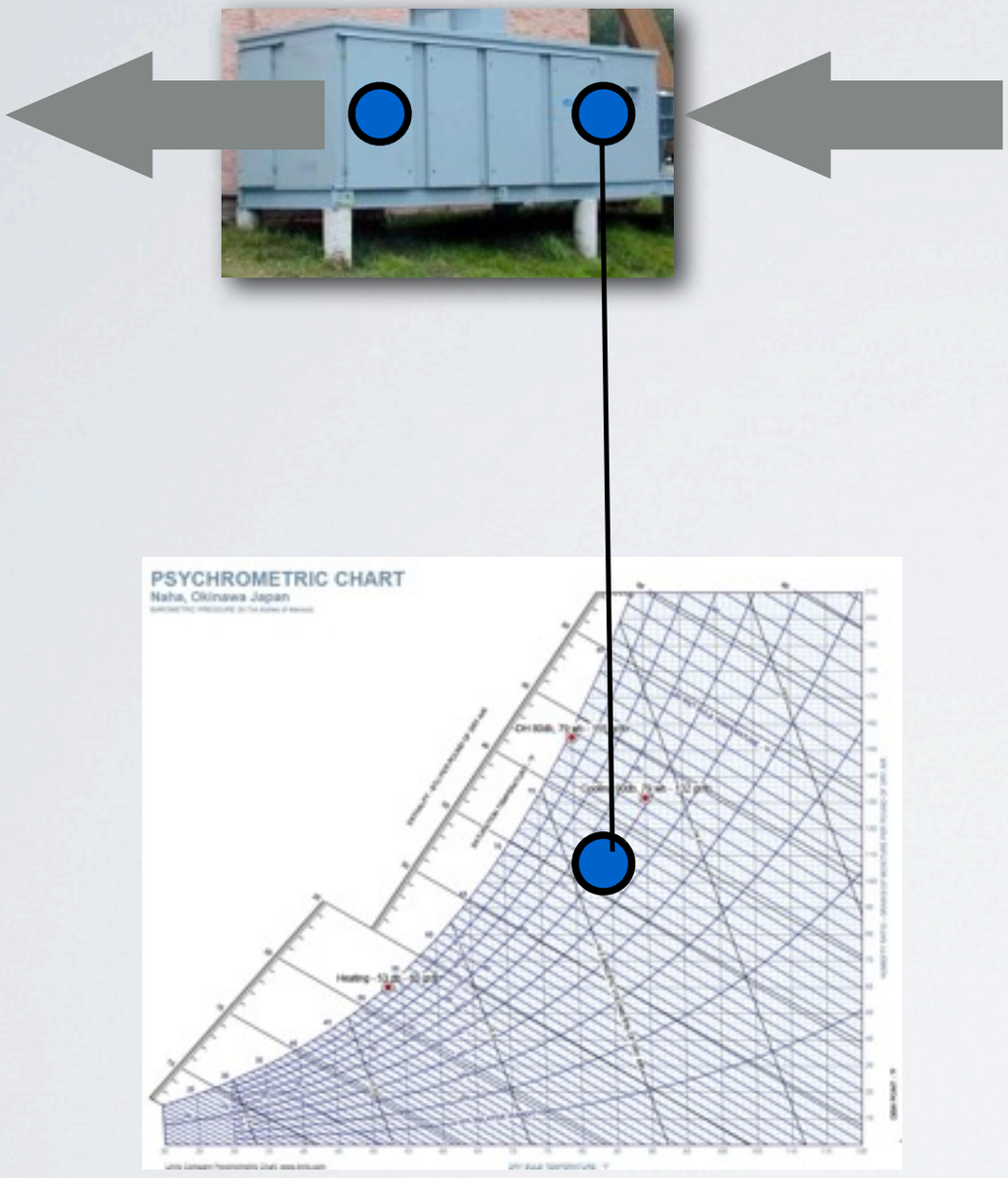


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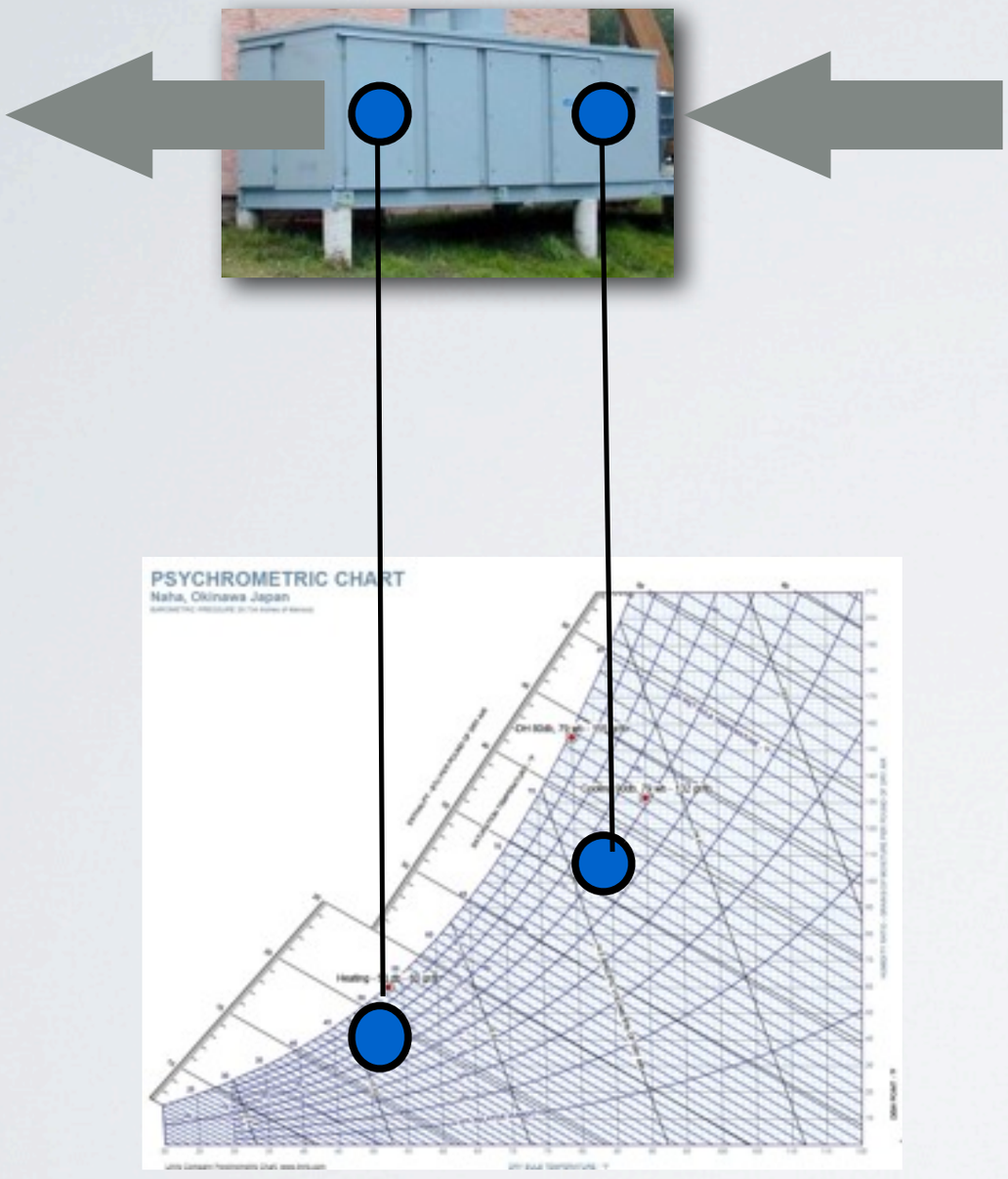


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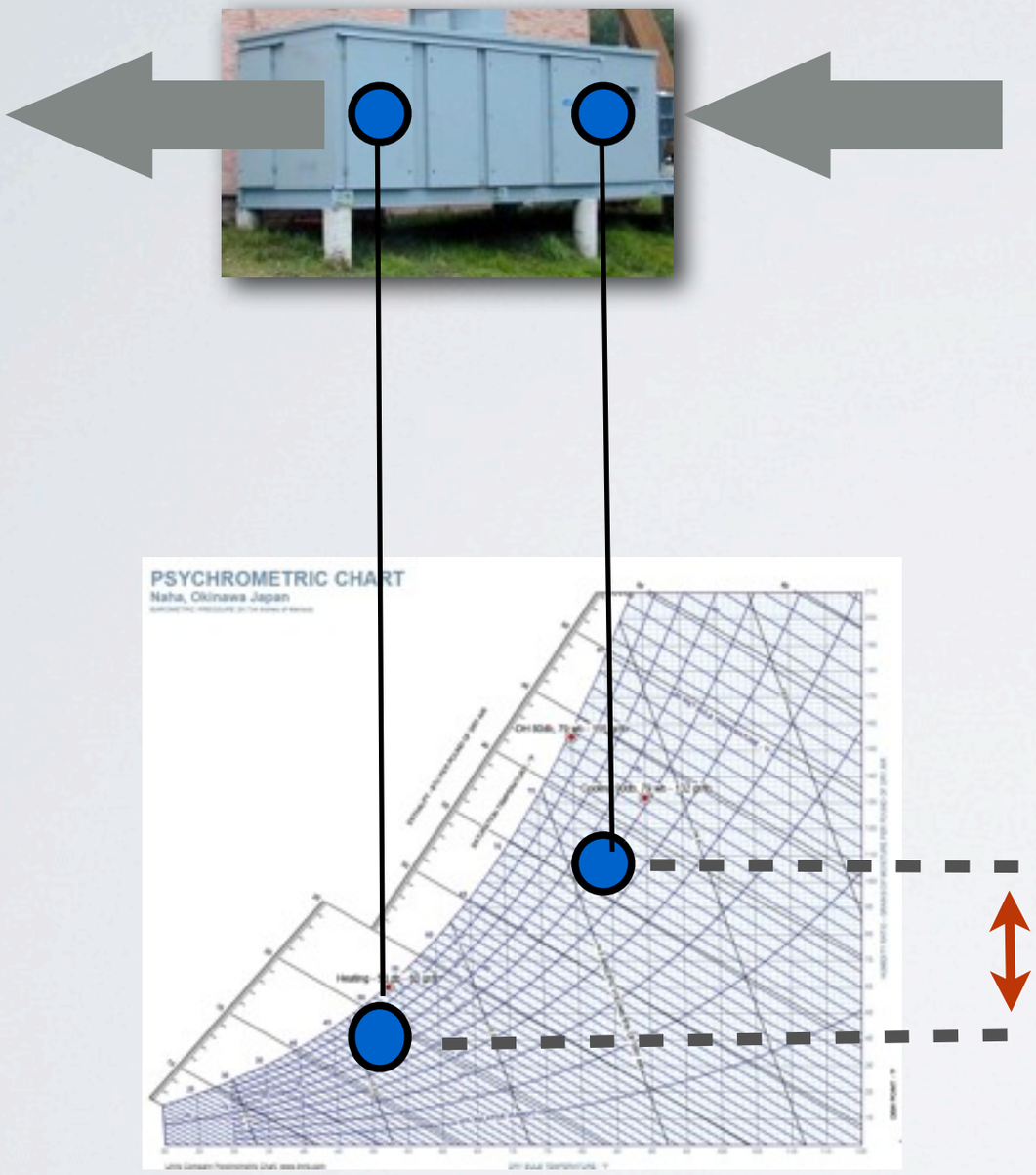


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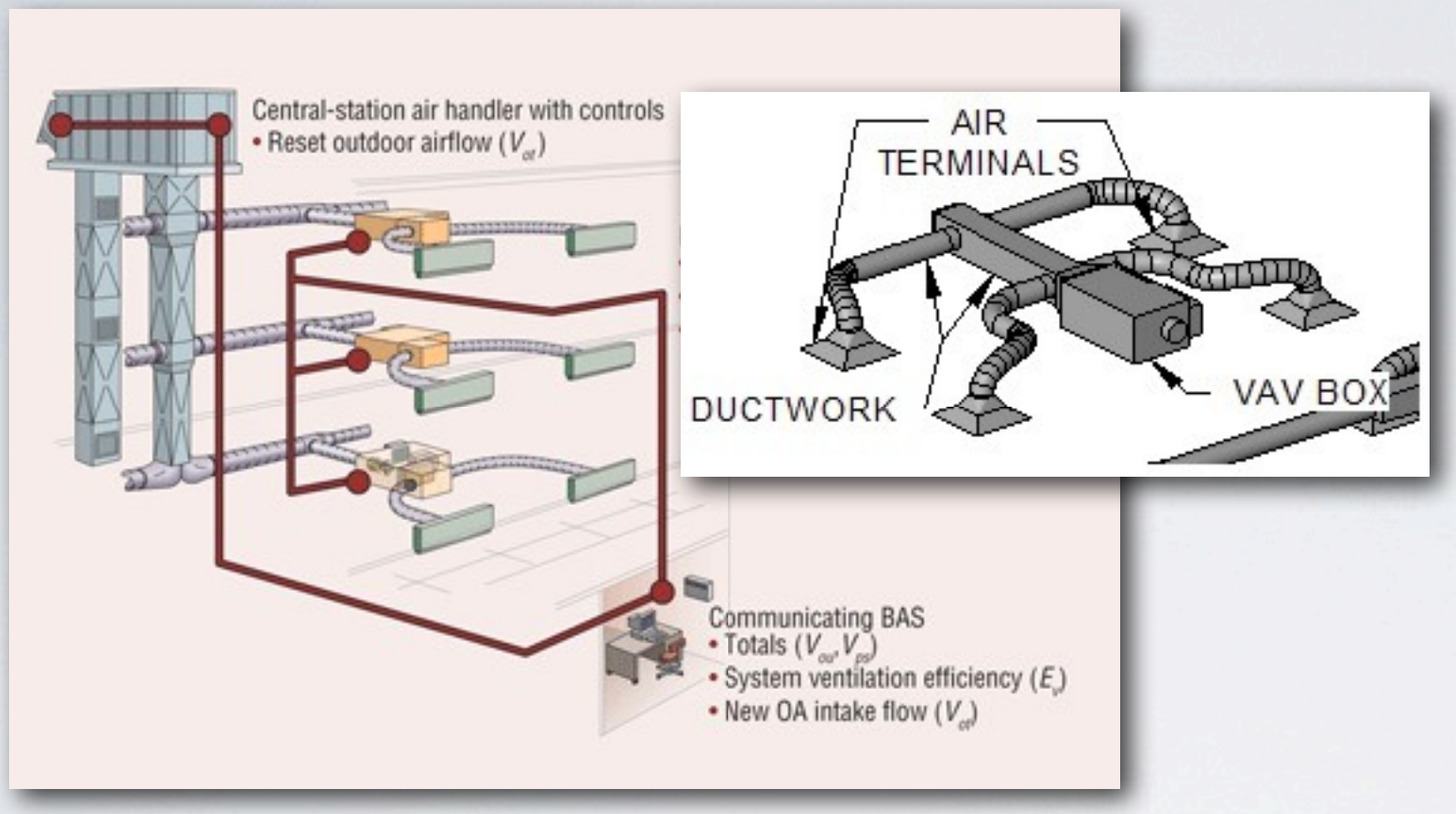

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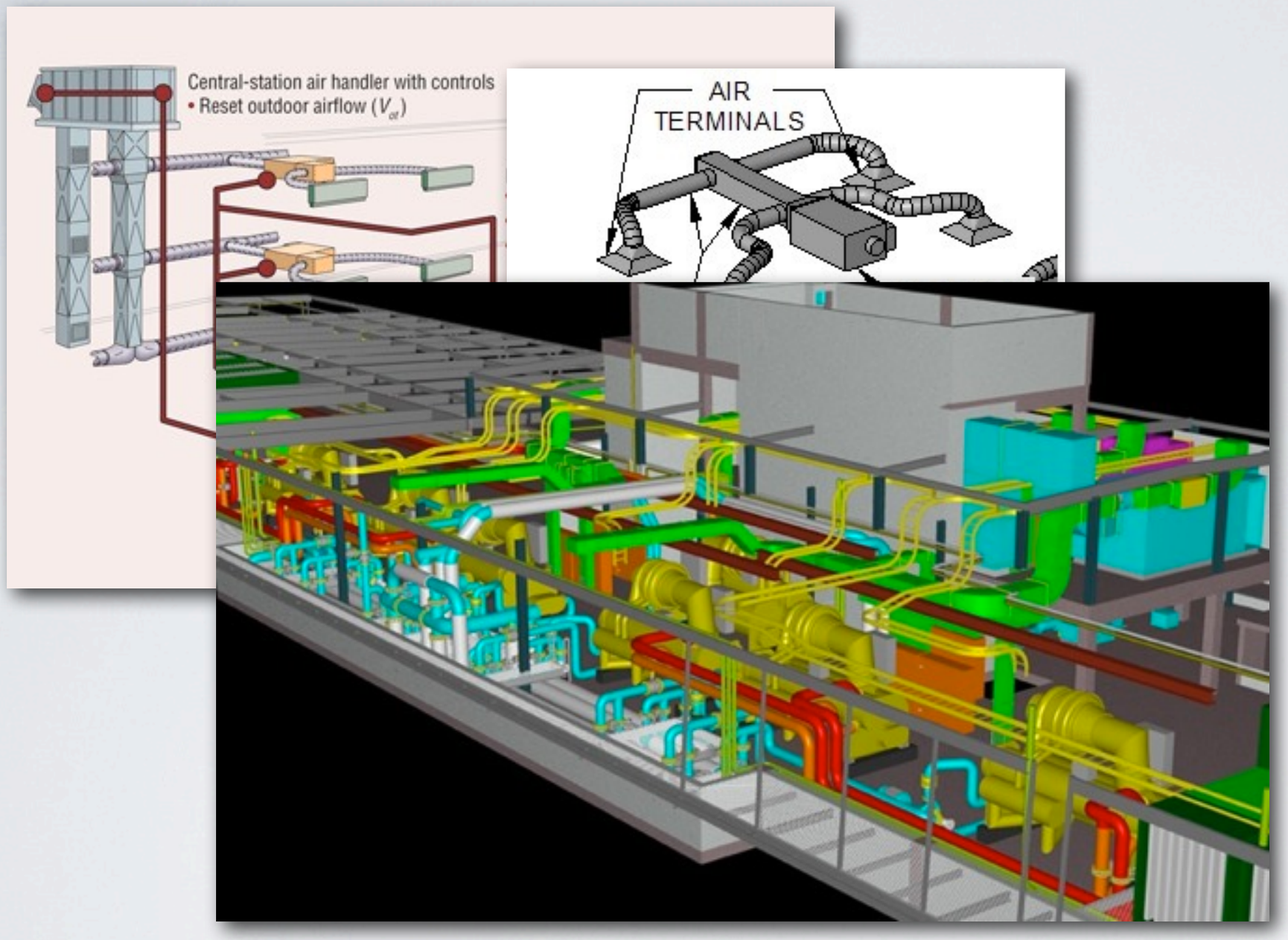

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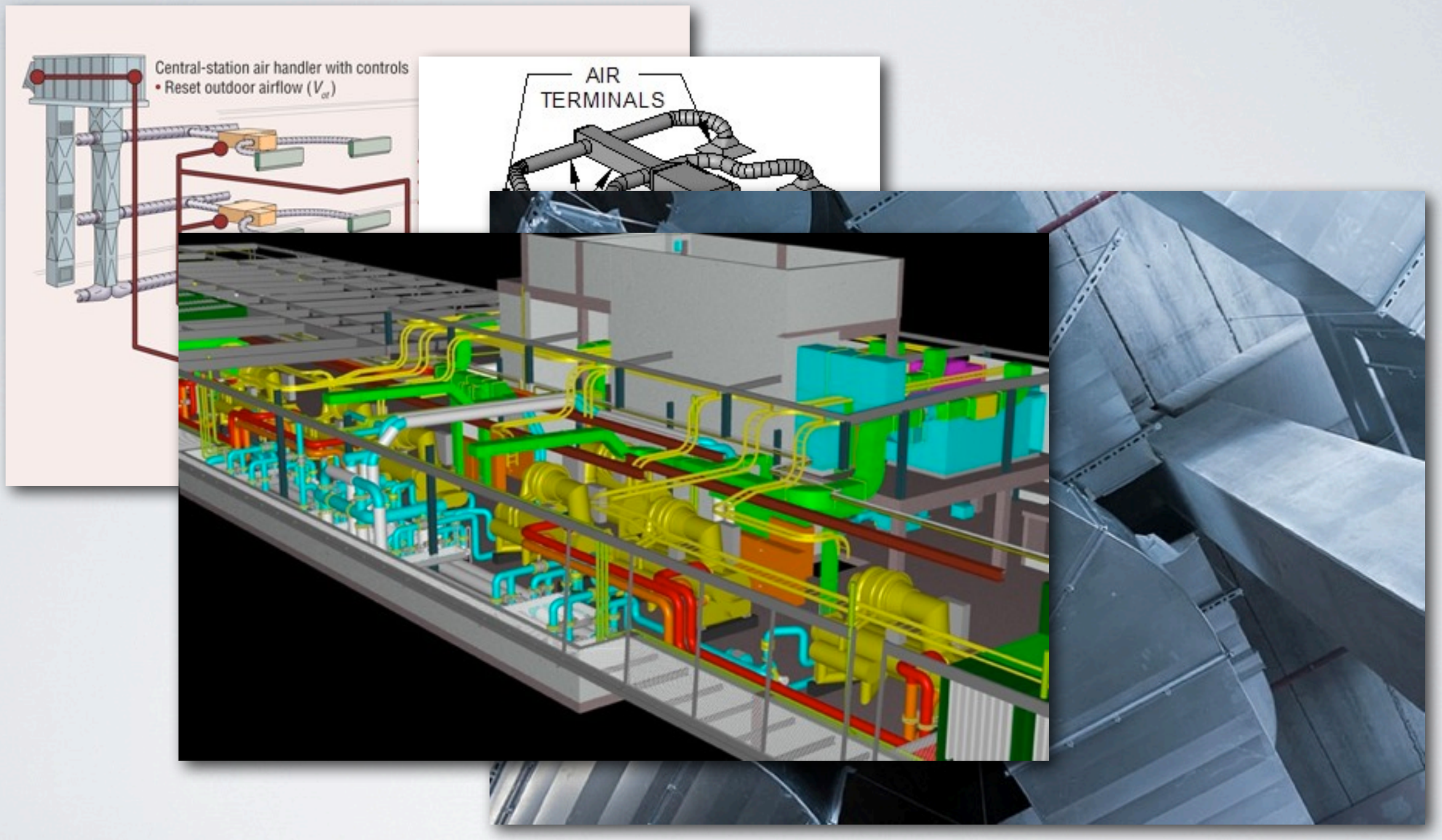

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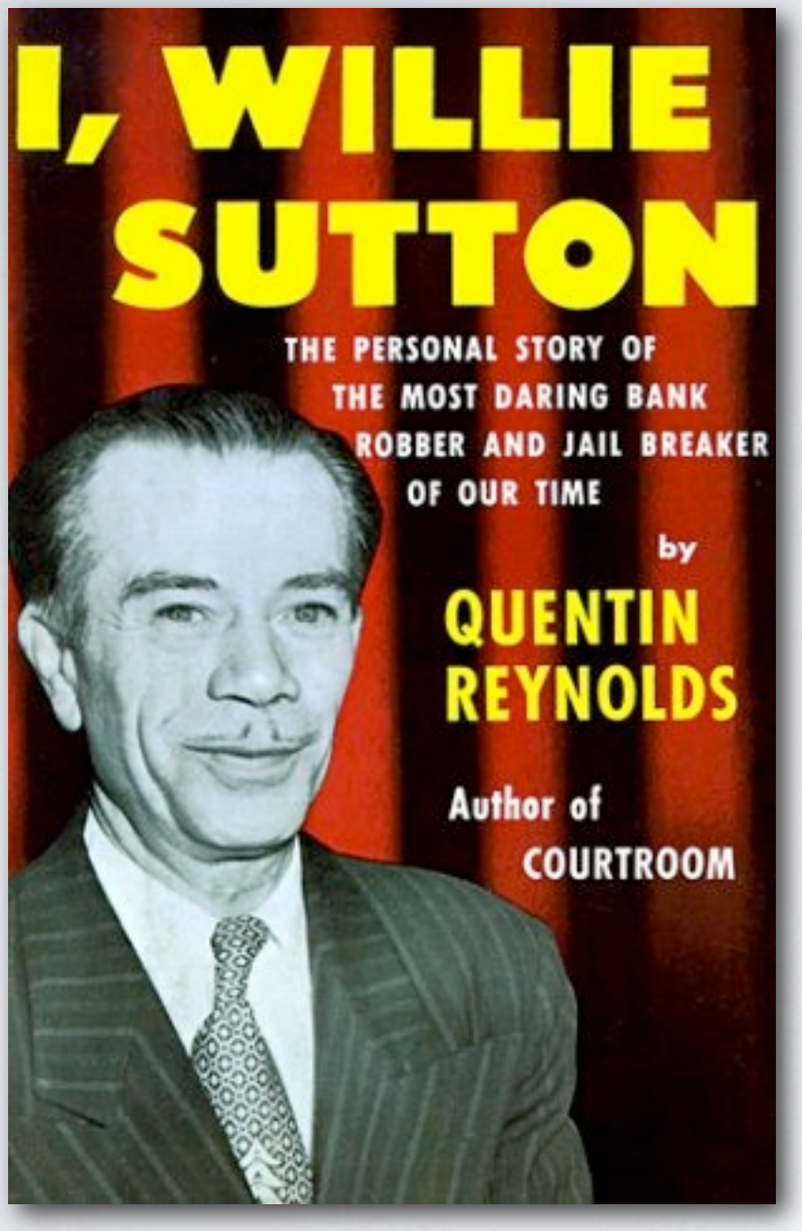

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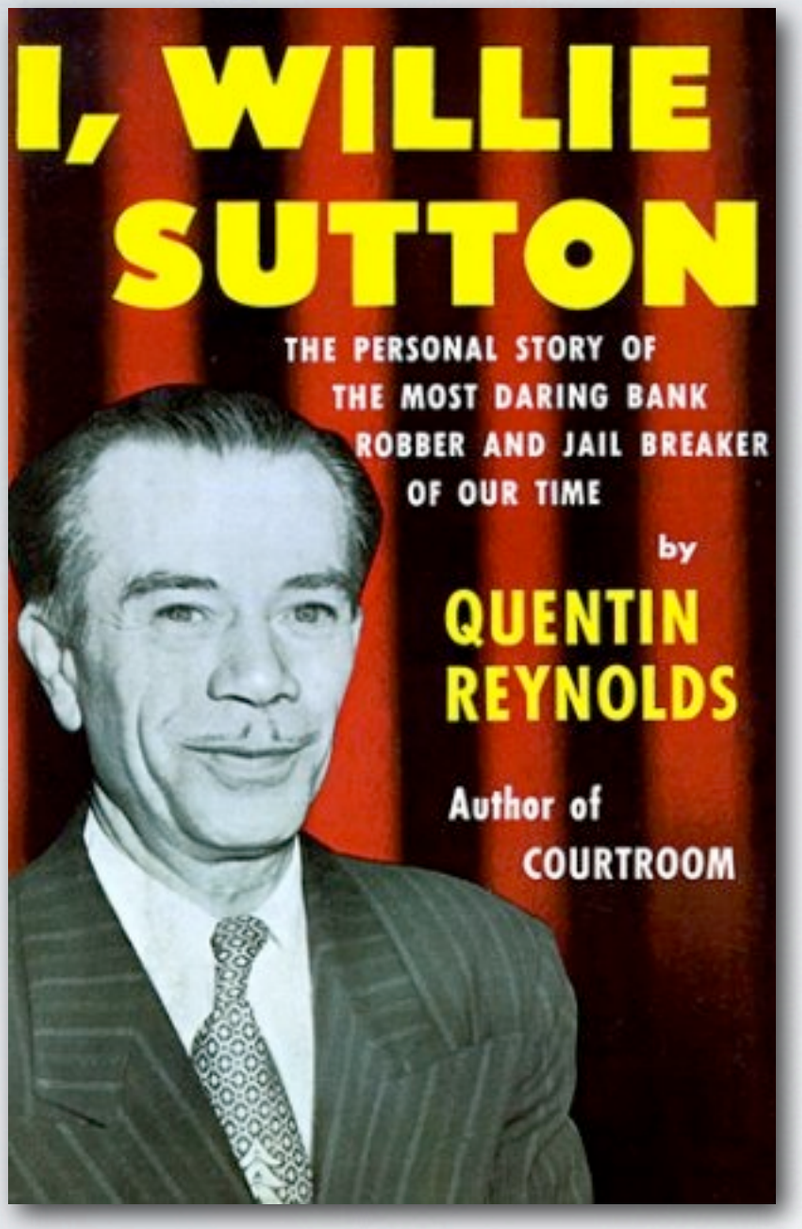


Reporter:

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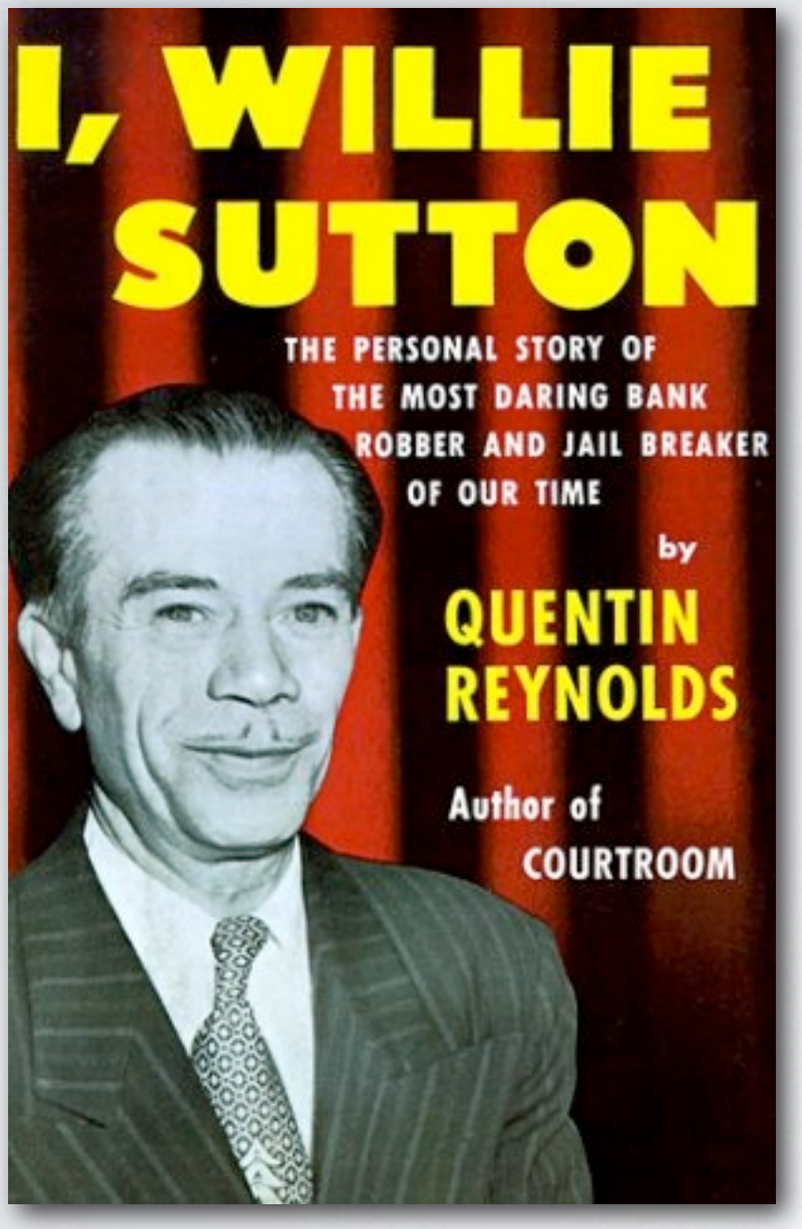


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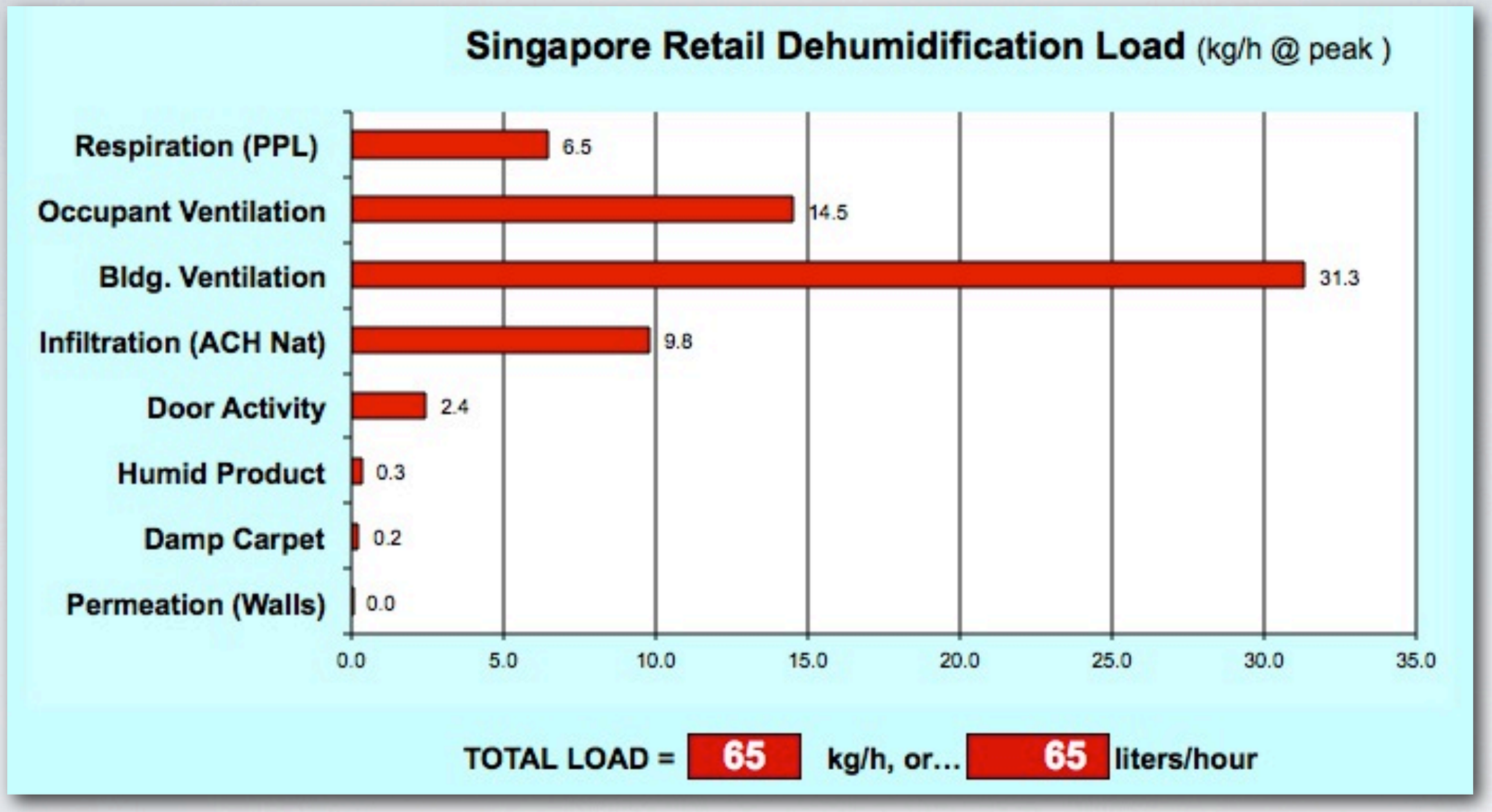

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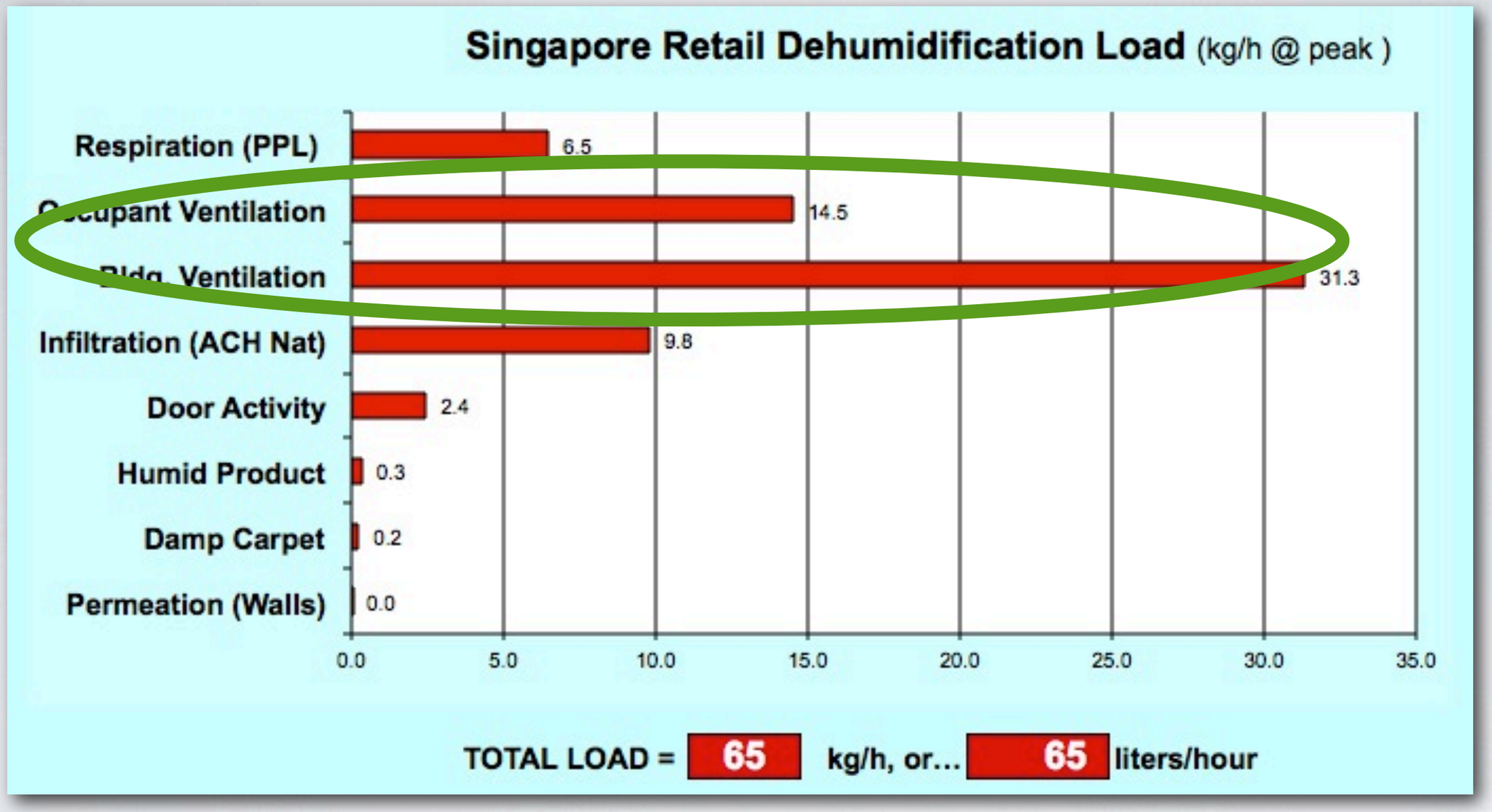

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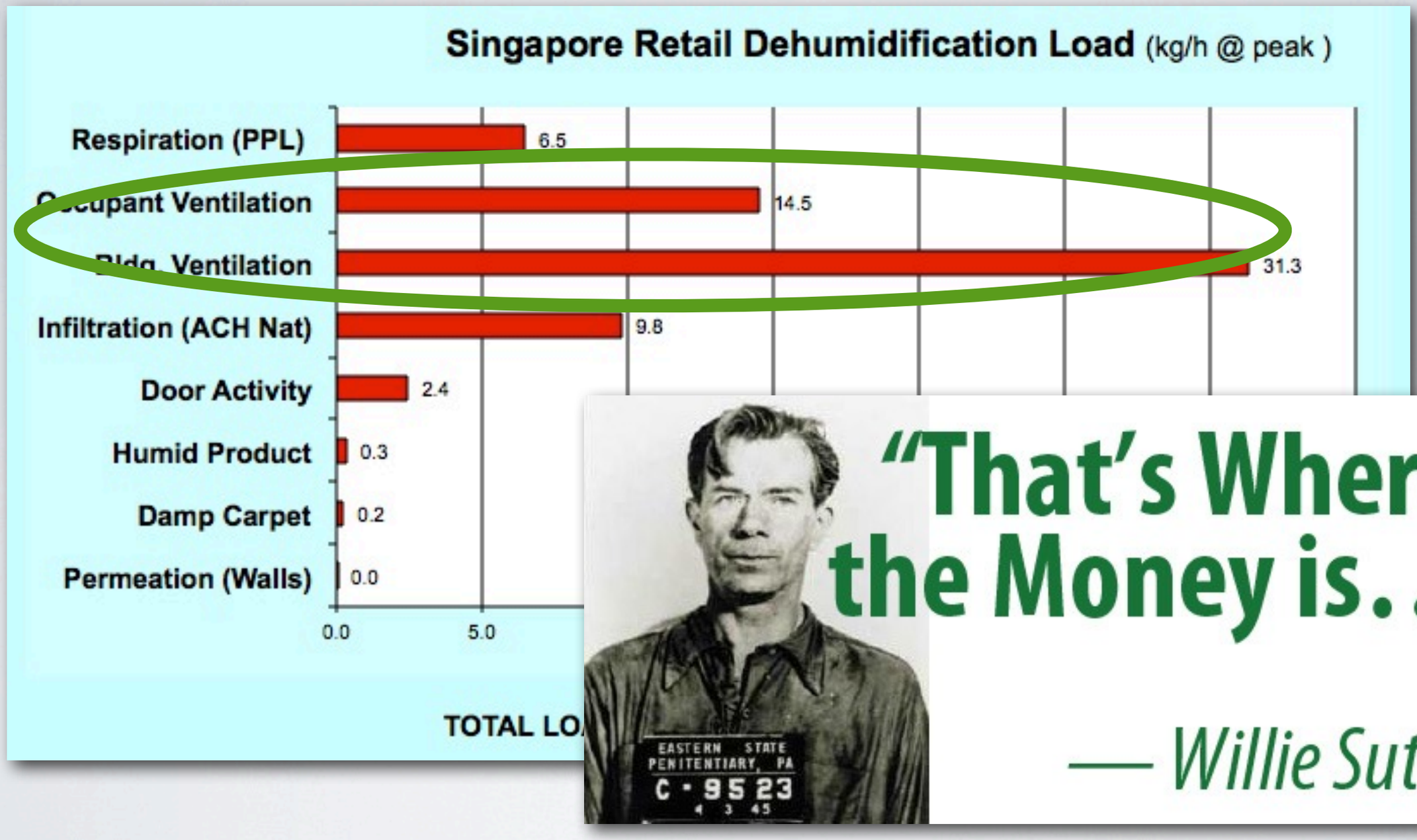
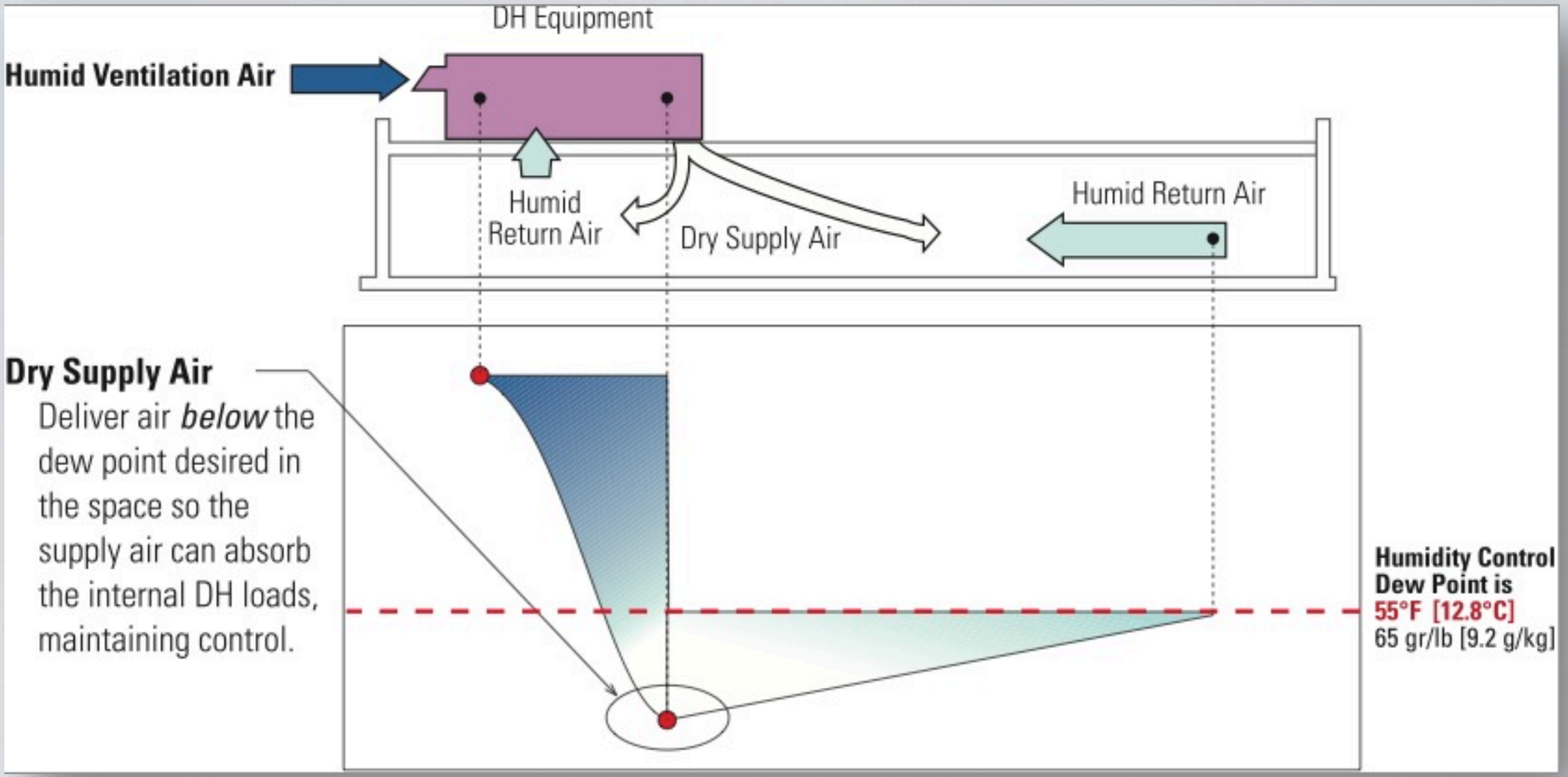
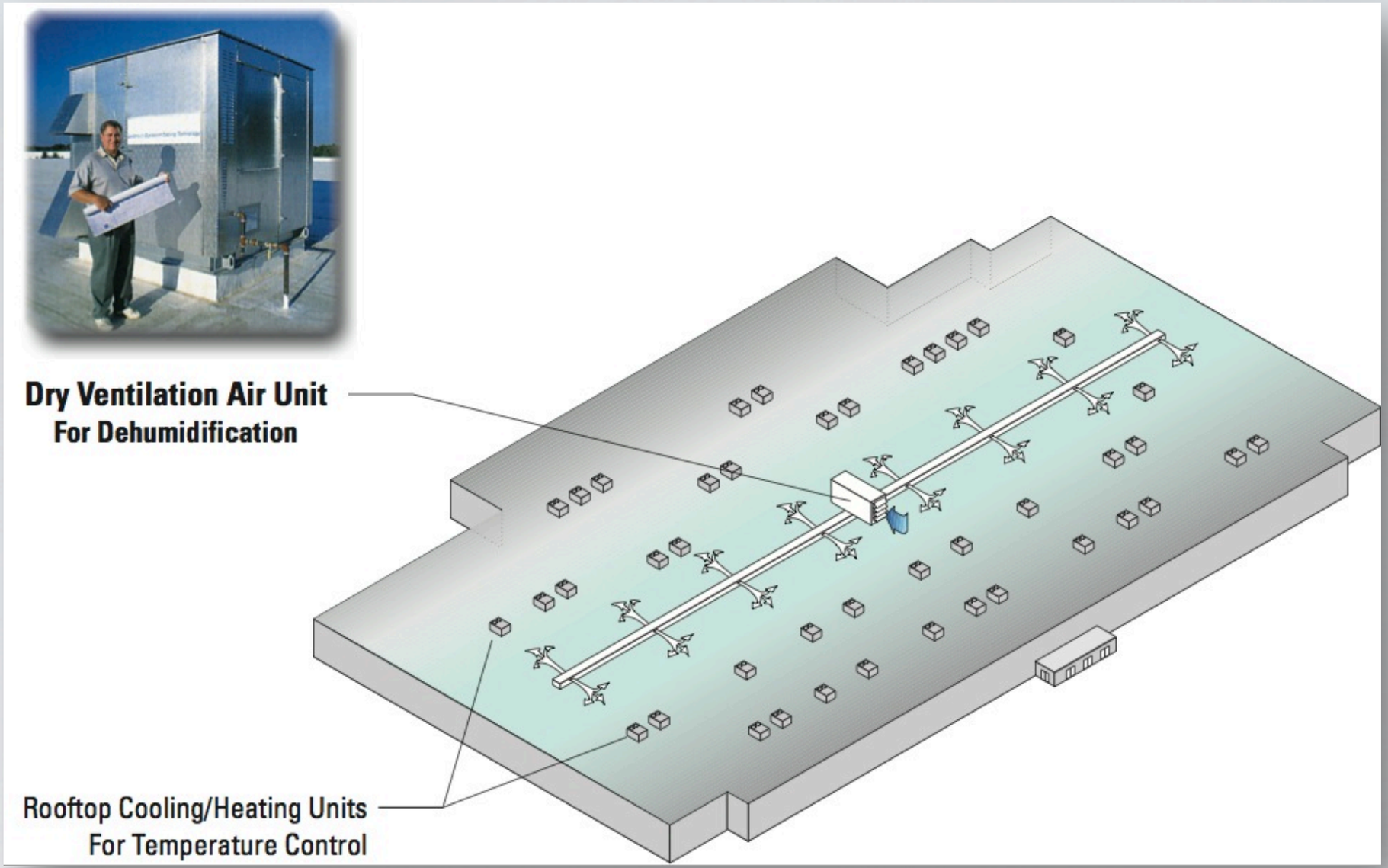


# Dry where the load is - DOAS controls humidity




Source: ASHRAE Humidity Control Design Guide - 2006

# Typical layout - Big box retail

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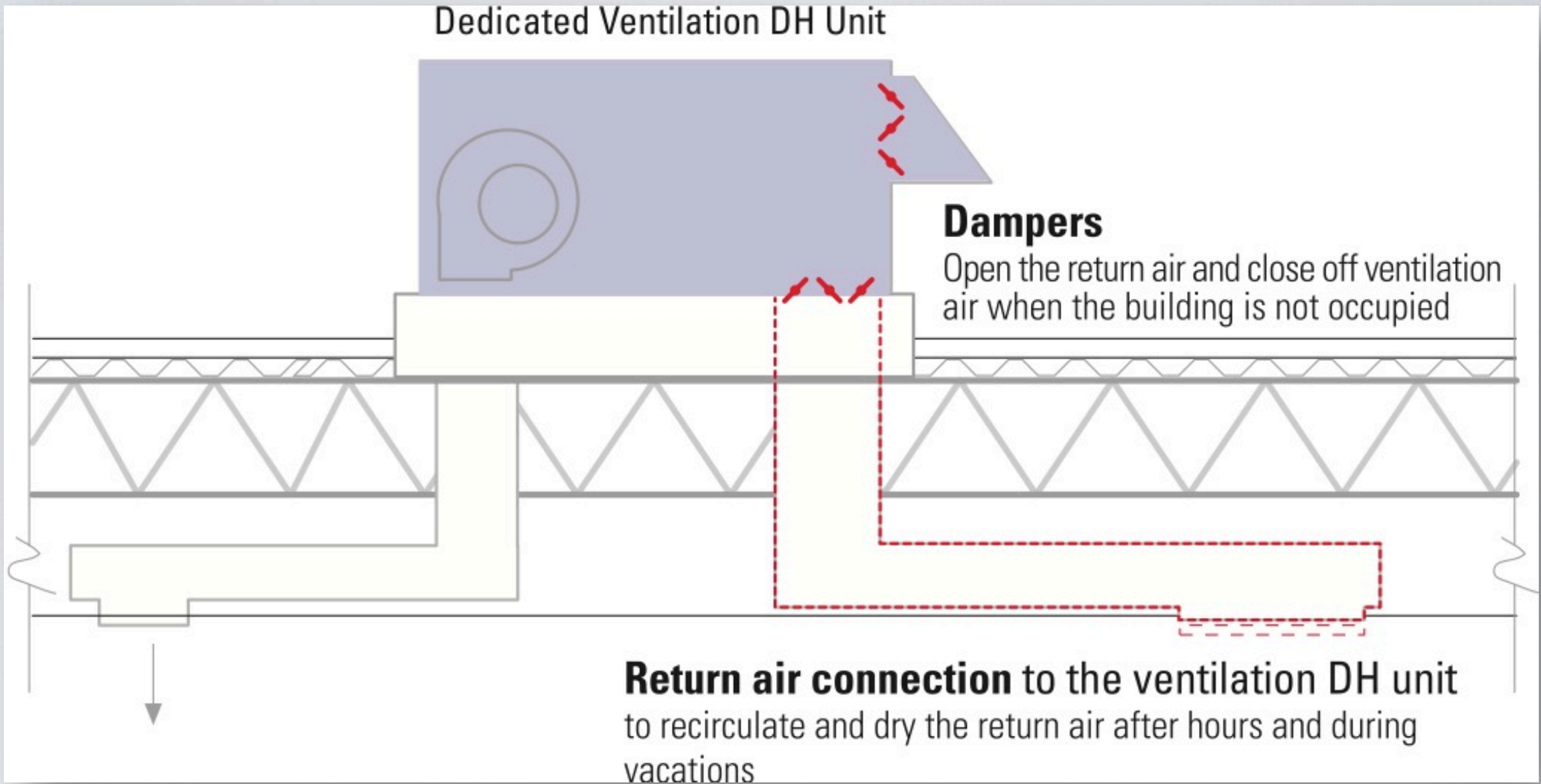
# Add return air connection for humidity control during unoccupied hours and vacations

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## Section 2b

# Common HVAC Design Shortcomings

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  - Long term - REPLACE large central exhaust systems with many small, locally-controlled exhaust and supply systems equipped with energy recovery devices

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**Measured Ventilation Air Flow - 510 Office Buildings**

ASHRAE Standard Requirement (At the time of measurement)
Excess ventilation

| | Per Person cfm/person [l/s/person] | Per Unit Floor Area cfm/ft2 [l/s.m2] | Air Changes Per Hour |
|---|---|---|---|
| Mean (Average) | **117** [55] | 0.4 [2.04] | 2.00 |
| Median (Most Common) | **63** [30] | 0.2 [1.03] | 0.98 |
| Standard Deviation | **158** [74] | 0.5 [2.54] | 2.45 |
| Std 62.1-1989 | **20 [9]** | 0.07 [0.36] | 0.34 |

Andrew Persily (NIST) "Ventilation demand and performance in U.S. office buildings" ASHRAE Journal

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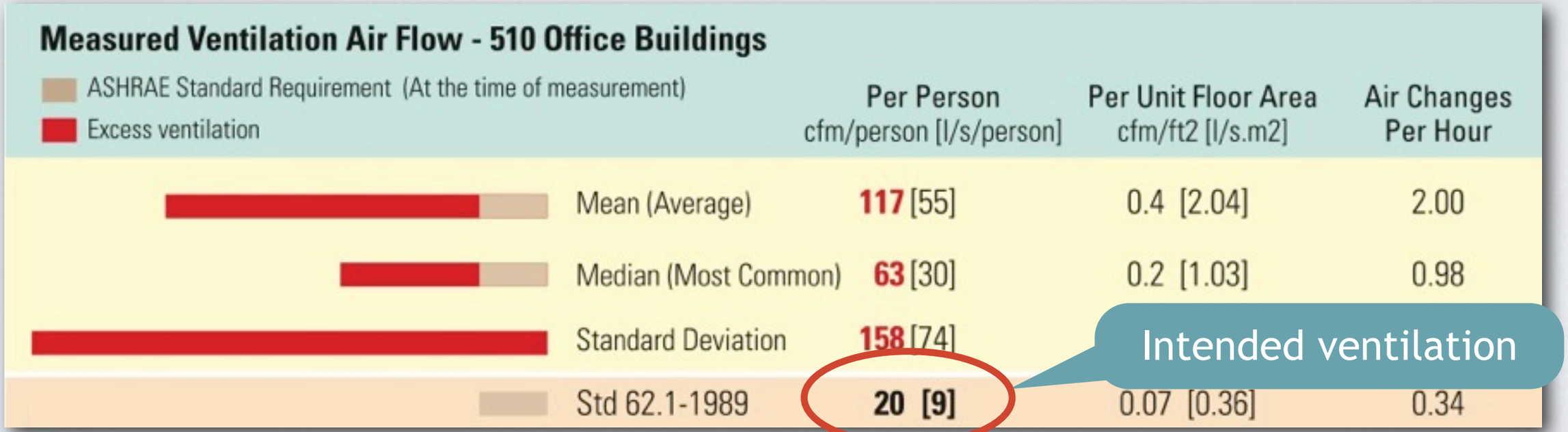


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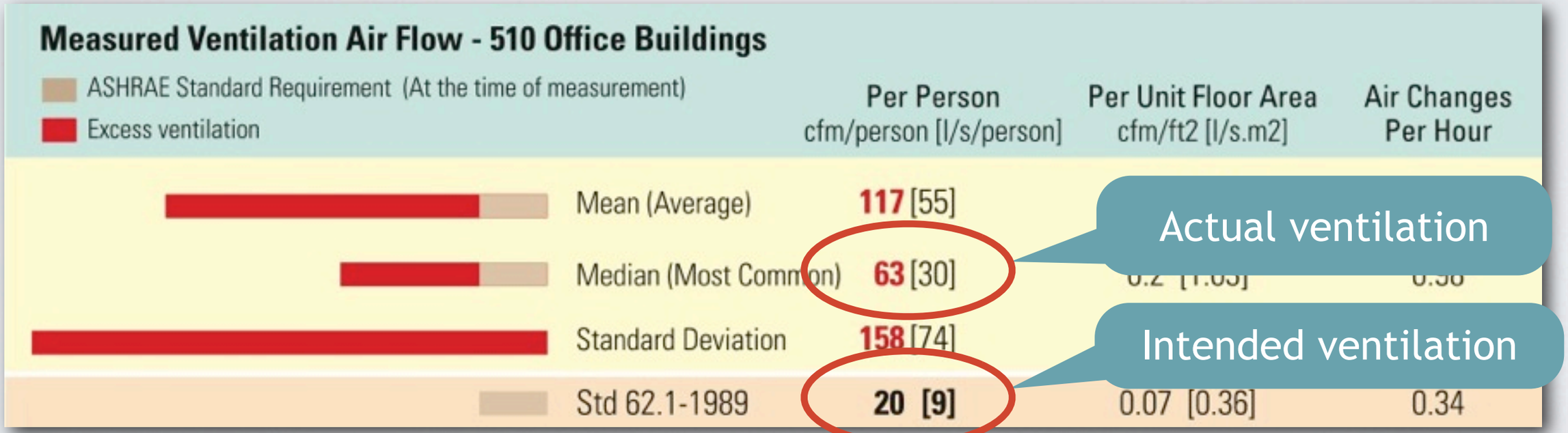


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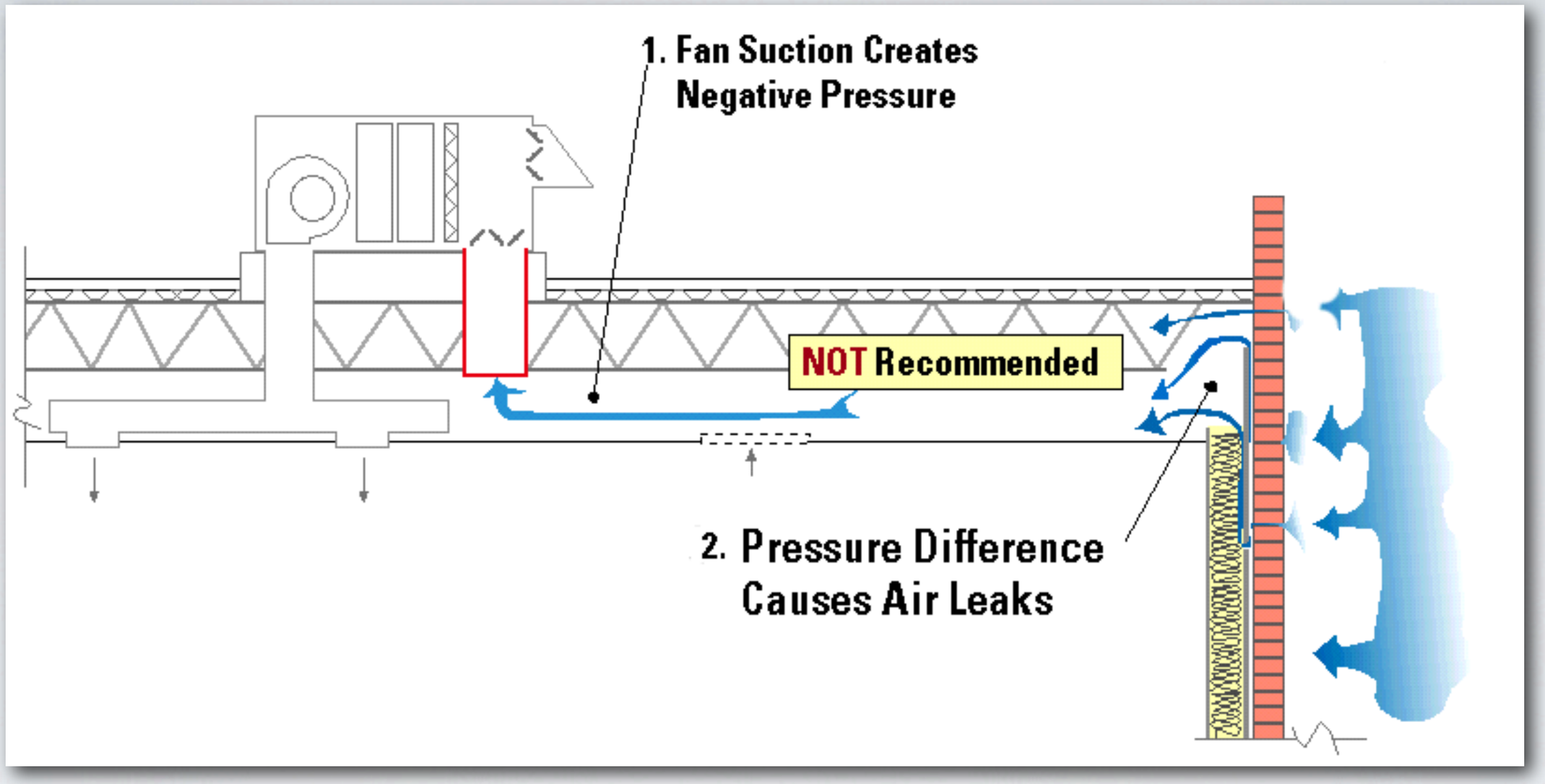
# Return plenums.. They leak a lot. It's a problem.



# Unsealed exhaust ducts pull humid air into the building from outdoors

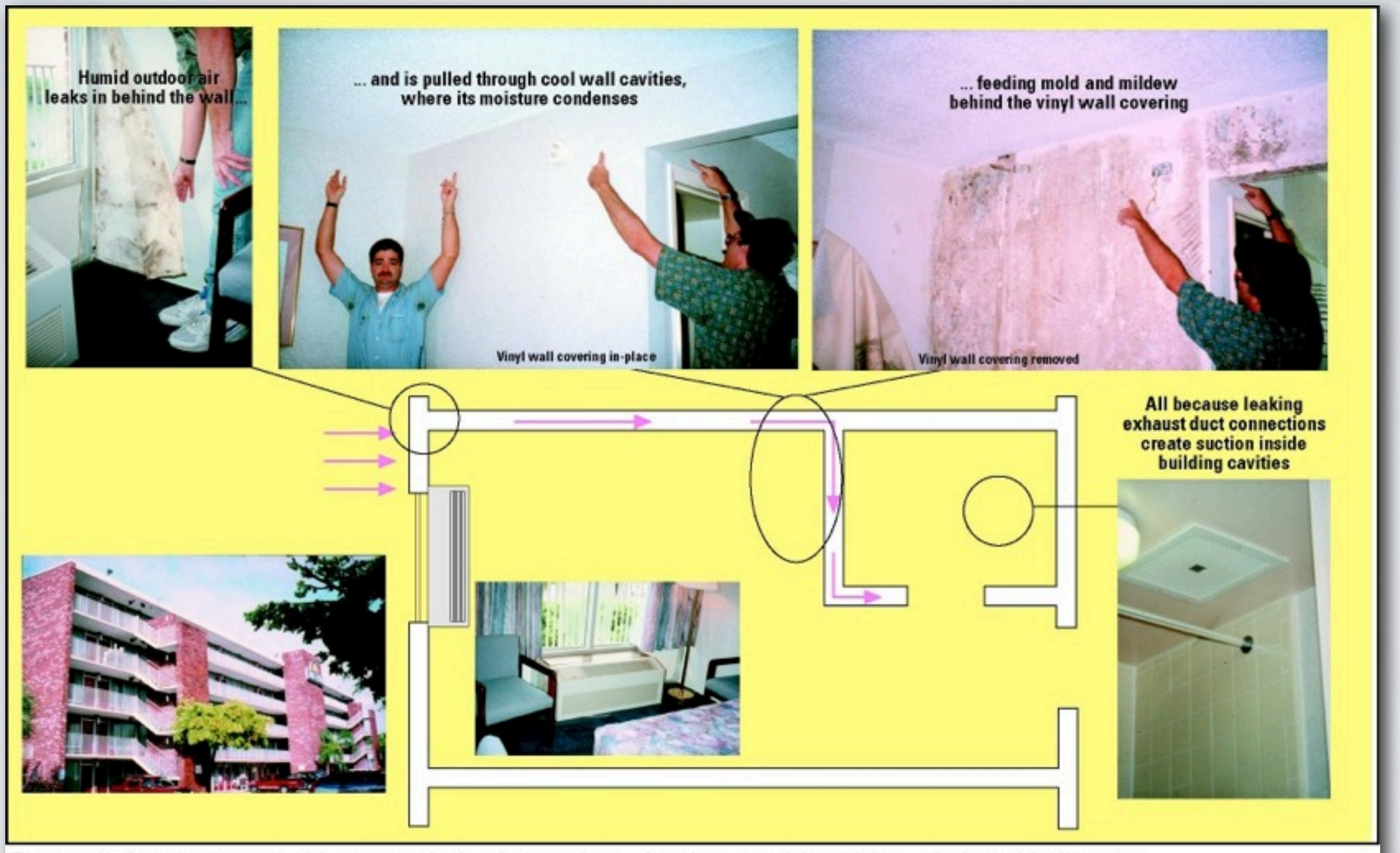
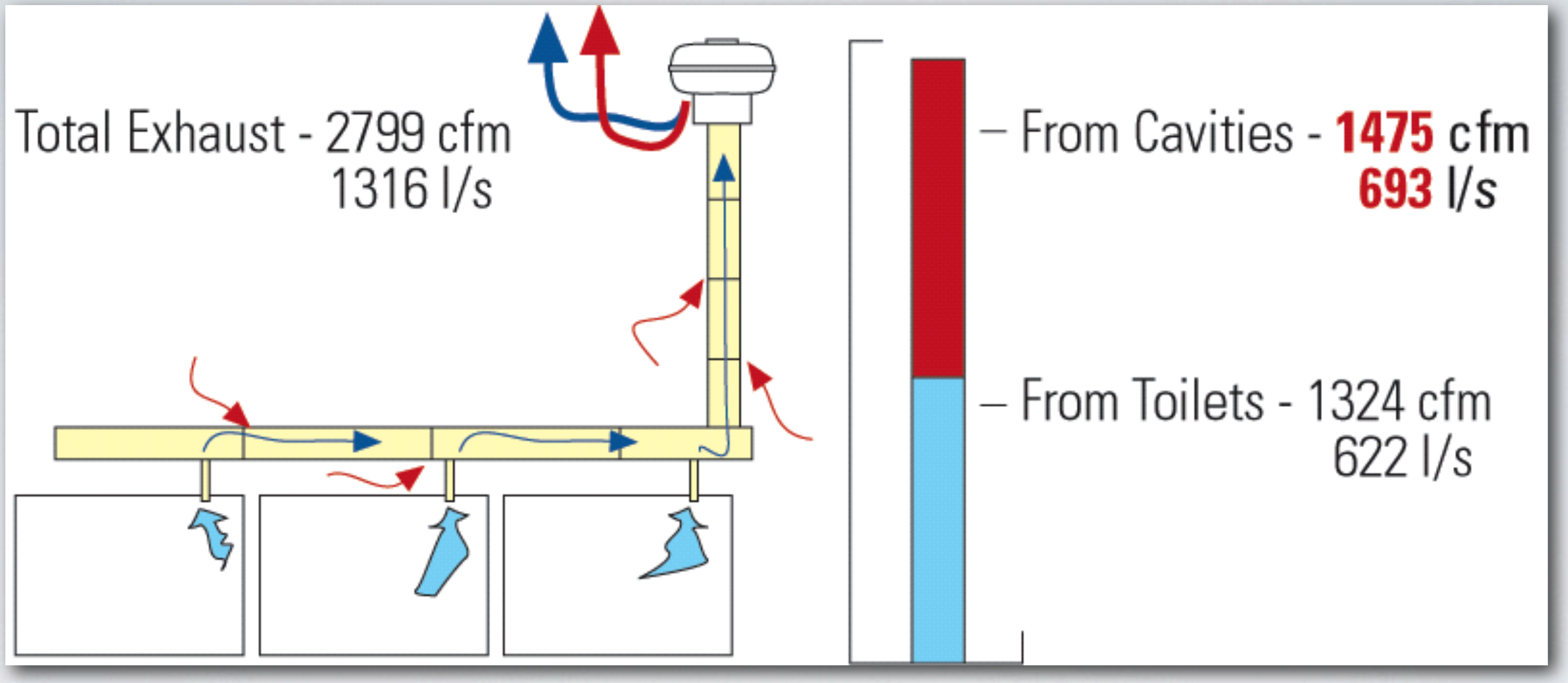



Figure 1: Suction created by unsealed exhaust ducts leads to mold problems in humid climates.

# How MUCH leakage from unsealed exhaust ducts?



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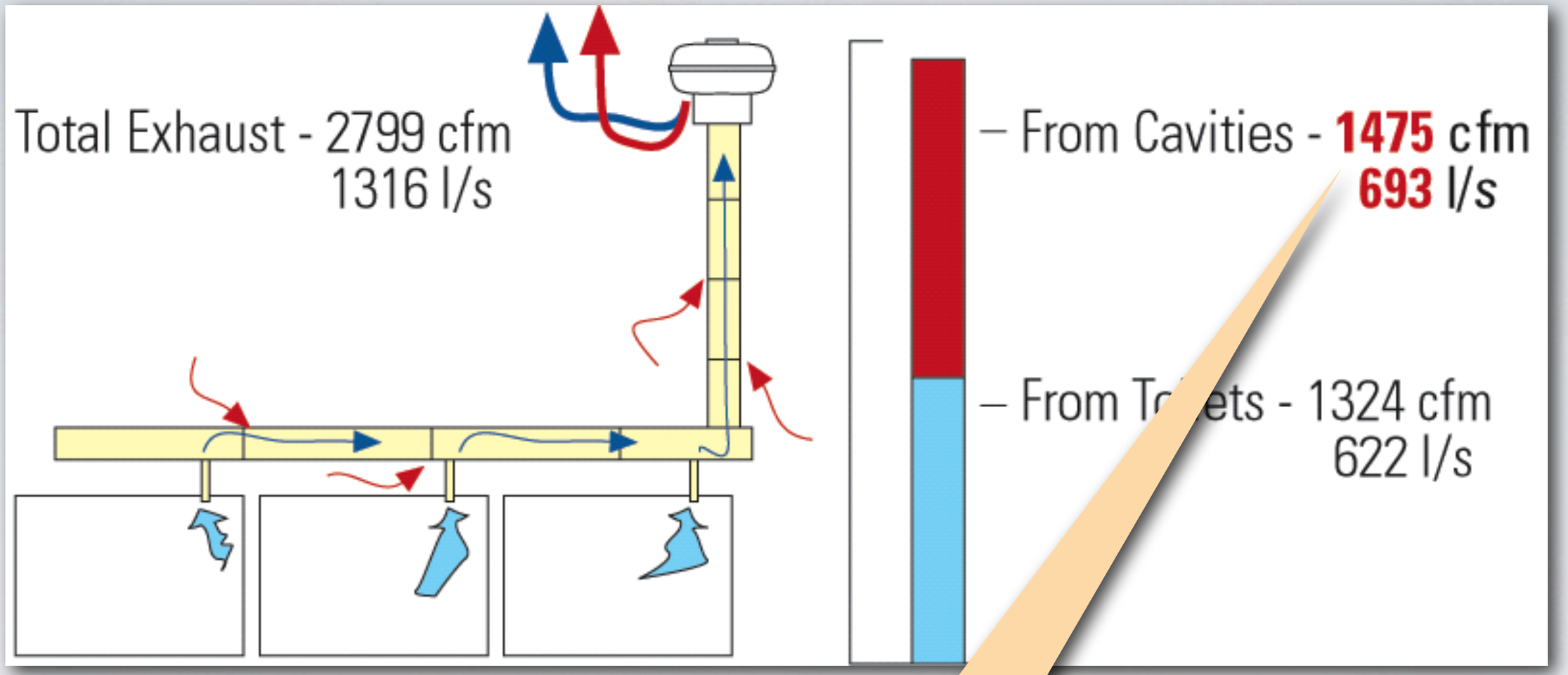


**More than 50% of exhaust is pulled from wall cavities—not the bathrooms**

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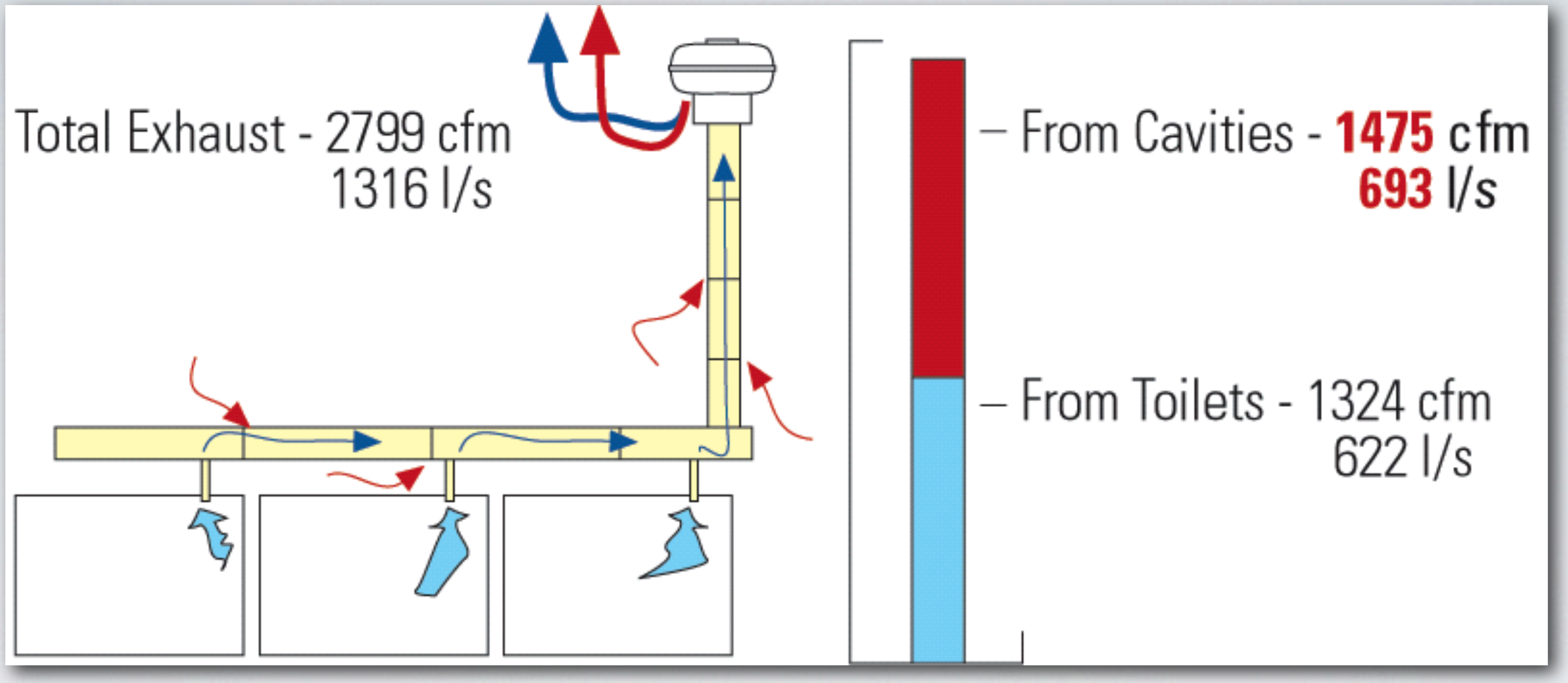

# Unoccupied hours - Problems and solutions



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Photograph 1: Mold growth on classroom wall aft



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Email Share Print A A A Text Size

**Clark County elementary school buildings closed indefinitely due to mold issues**

Recommend 2 recommendations. Sign Up to see what your friends recommend.

*Posted: Aug 15, 2011 4:00 PM EDT*

CLARK COUNTY, Mo. (WGEM) --A serious mold problem is delaying the first day of school for about 450 Clark County students. The school district has decided to start classes Monday for those students at the district's high school and middle



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- **Building is partly occupied - A few rooms are cooled, most are not. Mold grows on cold surfaces**

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- **Building is partly occupied - A few rooms are cooled, most are not. Mold grows on cold surfaces**
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# Problems during unoccupied hours (2 of 2)

- **Ventilation air continues when indoor temperature set point is raised, flooding building with humid air**
  - Short term - Install motorized dampers to close off ventilation air when building is unoccupied.
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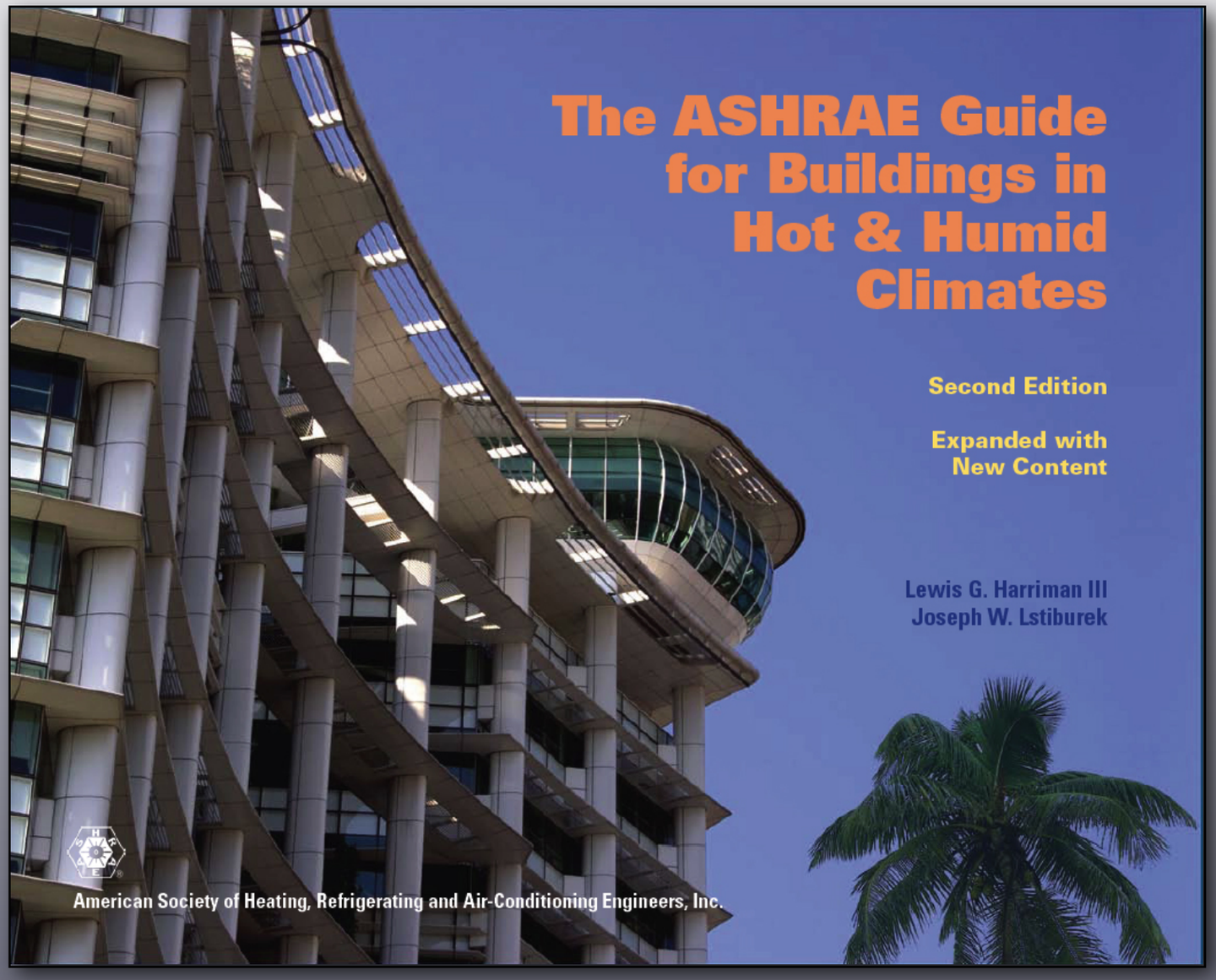
- For easy humidity control - Dry the incoming air in a dedicated outdoor air system (DOAS)

## Section 3 of 3

# Suggestions for Buildings



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**Joseph W. Lstiburek, Ph.D, P.Eng.**

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1. Introduction
2. Improving Thermal Comfort
3. Managing Ventilation Air
4. Reducing Energy Consumption
5. Avoiding Bugs, Mold & Rot
6. Improving Sustainability

## Enclosure Design

7. The Components of a Perfect Wall
8. Keeping Water Out of the Building
9. Keeping Heat Out of the Building
10. Architectural Lessons From Tropical Storms

## HVAC Design

11. Estimating Dehumidification Loads
12. Estimating Cooling Loads
13. Designing Dehumidification Systems
14. Designing Cooling Systems
15. Designing Ventilation Systems
16. Air-Tight HVAC Systems

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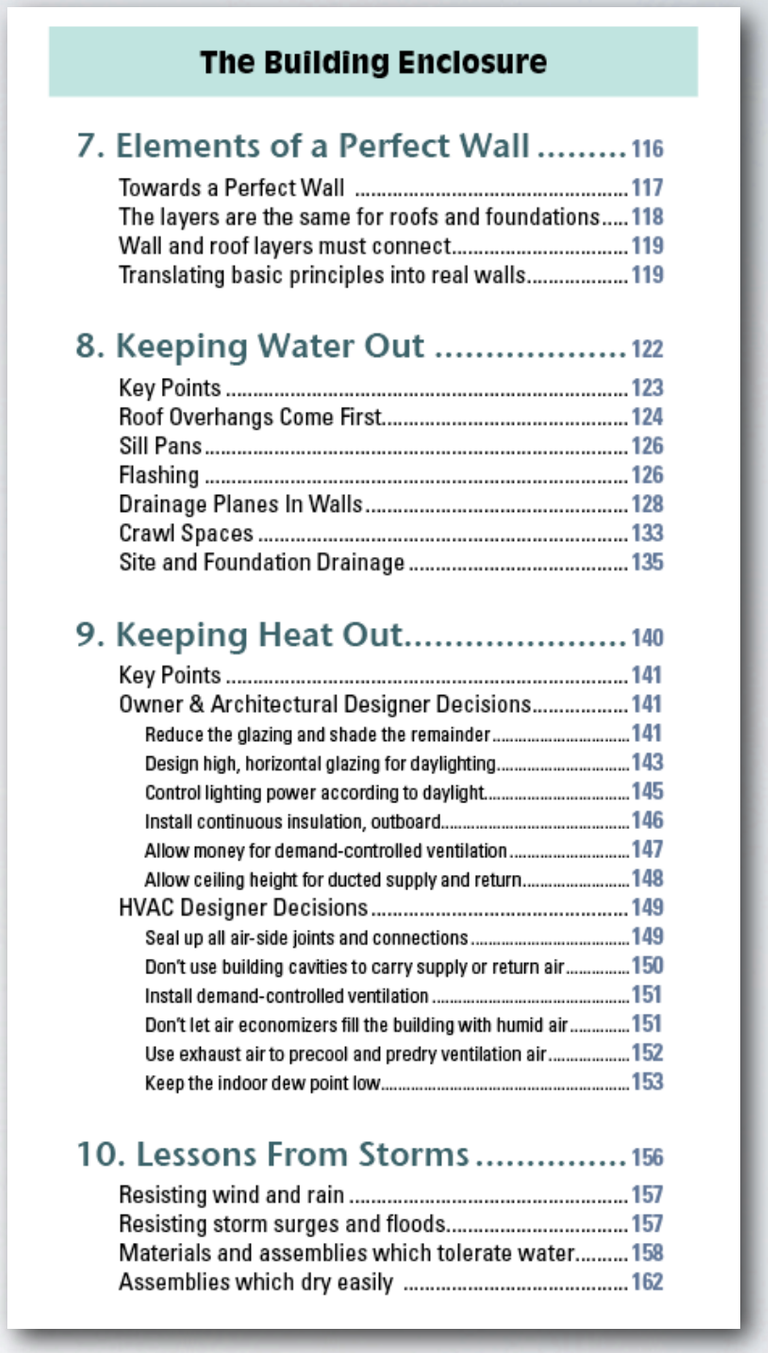

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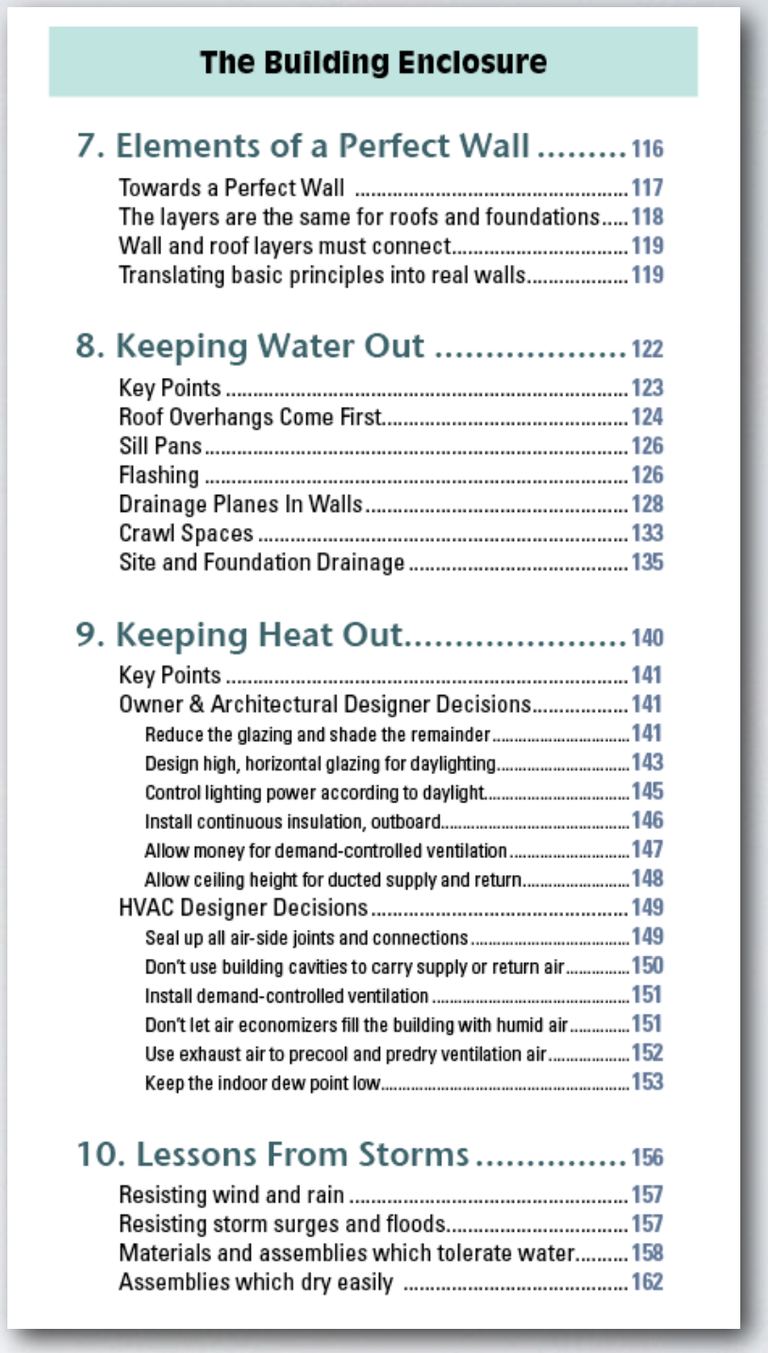
## 3 of My Favorite Suggestions:



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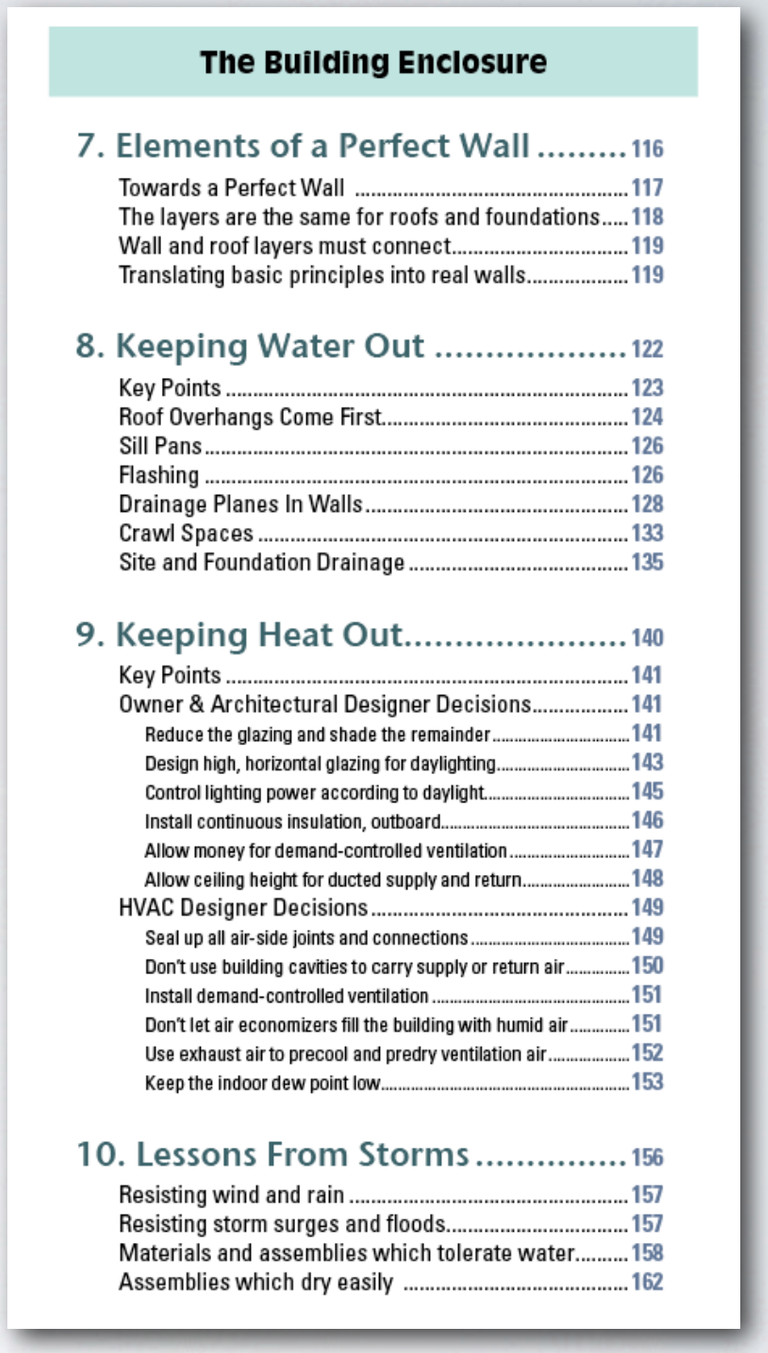
- **Focus on glazing**... Daylighting and low solar heat gain.



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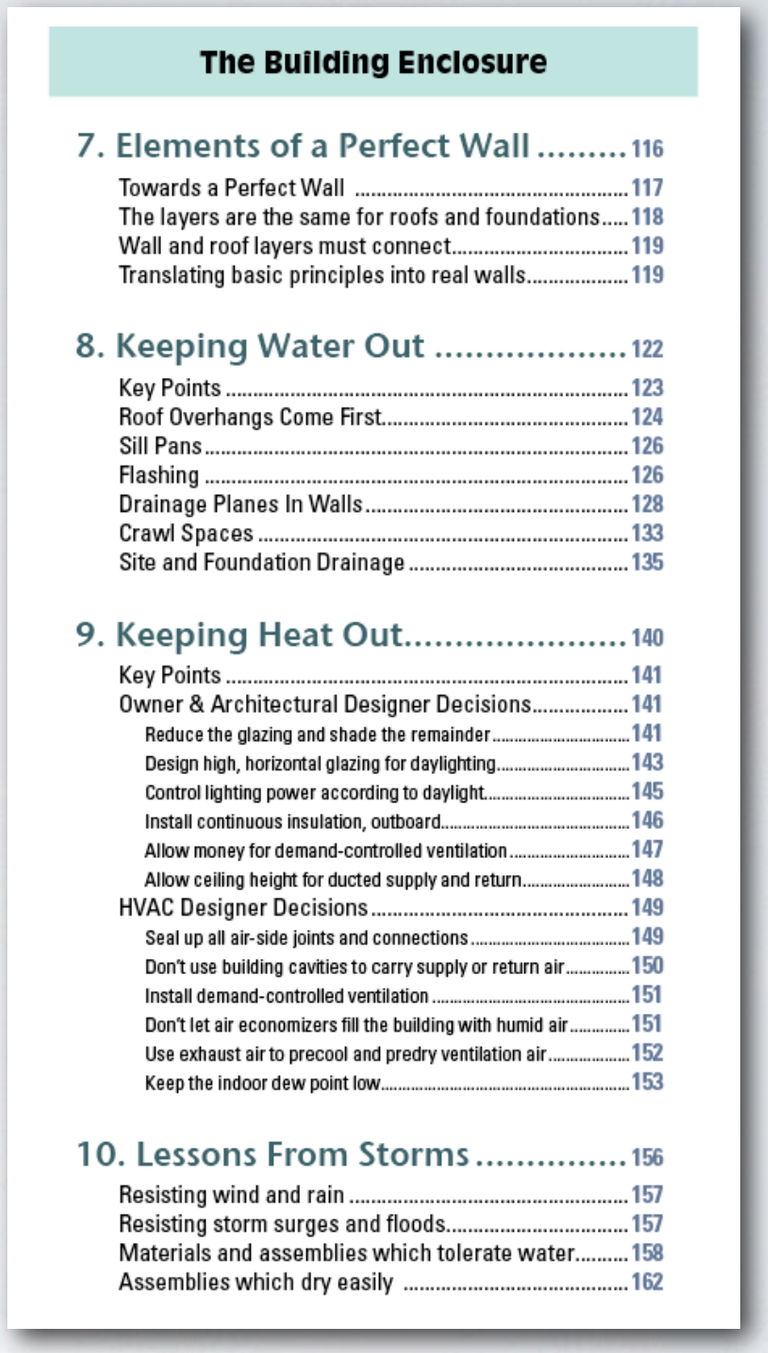
# Suggestions for architectural design

## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.



**The Building Enclosure**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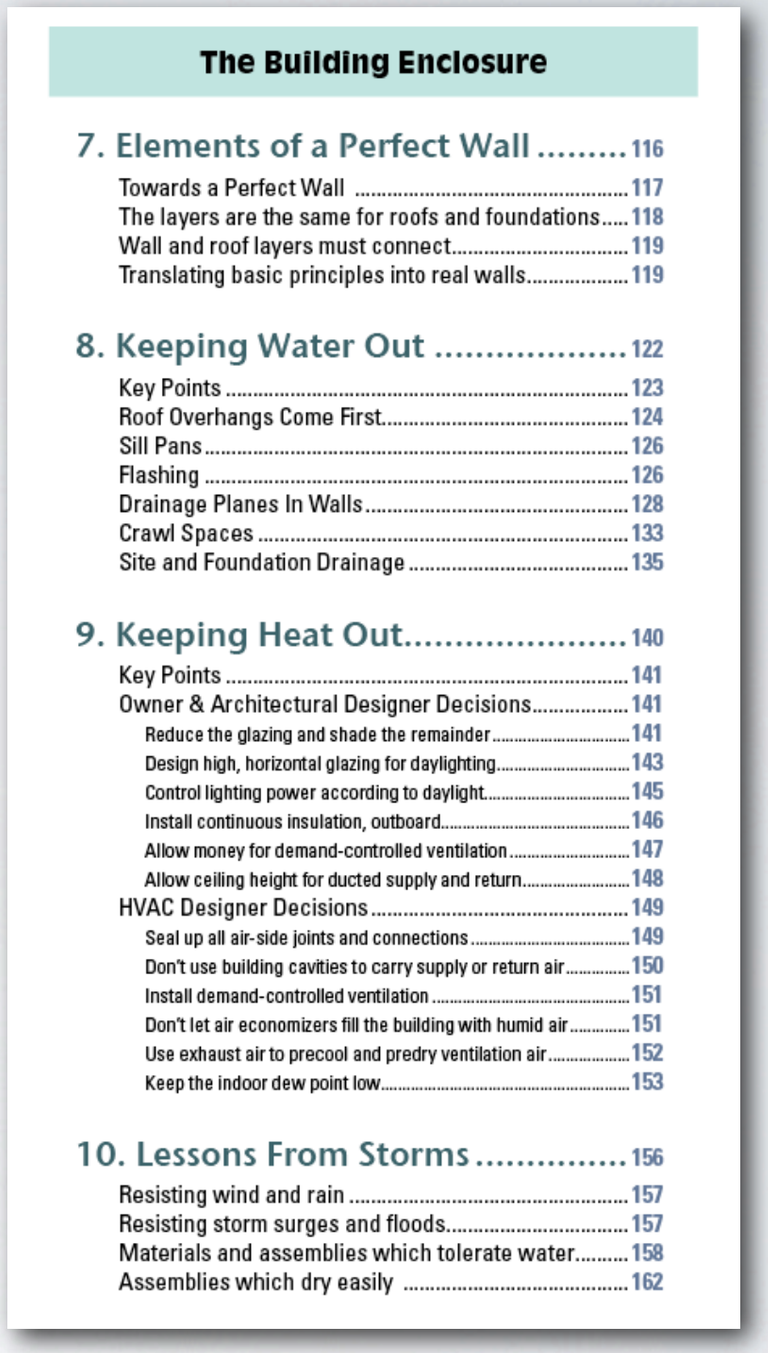
# Suggestions for architectural design

## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.
- **Indoor insulation and air tightness**... For partly-cooled buildings.



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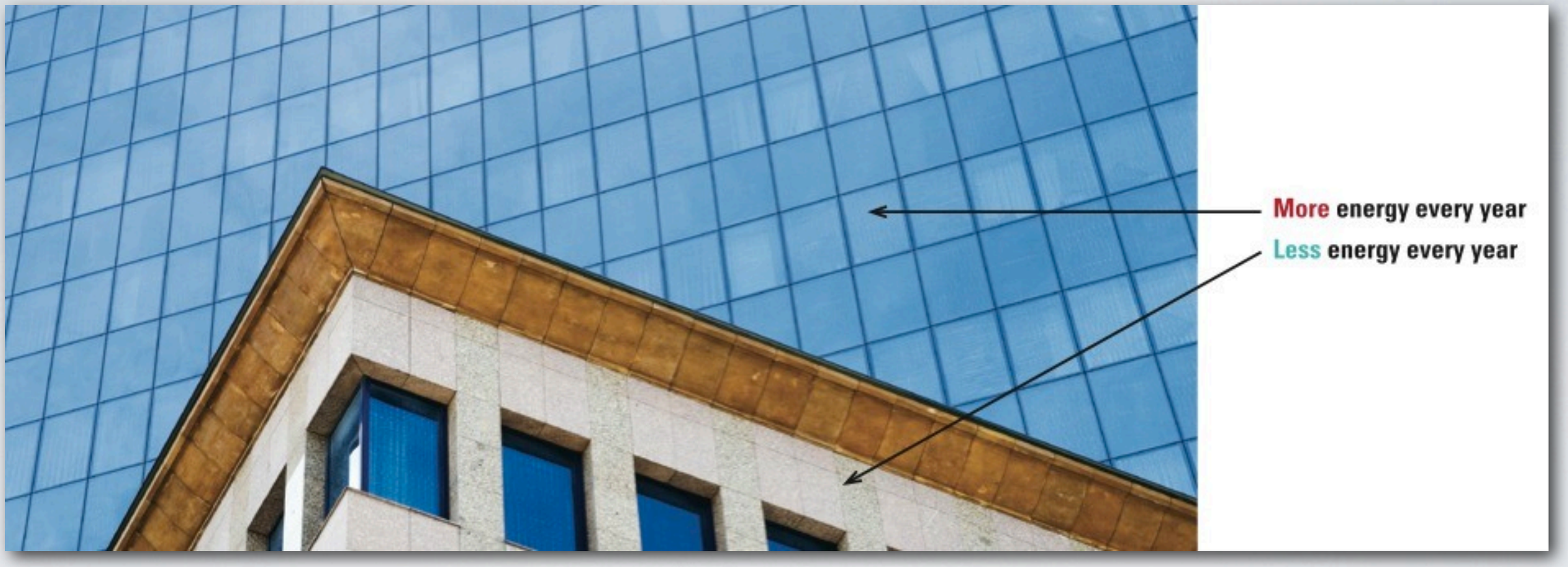
# Less glass = smaller cooling system = less energy!



# Time of day and air temperatures



# Time of day and air temperatures






# Time of day and air temperatures









# Manila - Shangri-La Hotel



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# Manila - Shangri-La Hotel - Surface temperatures



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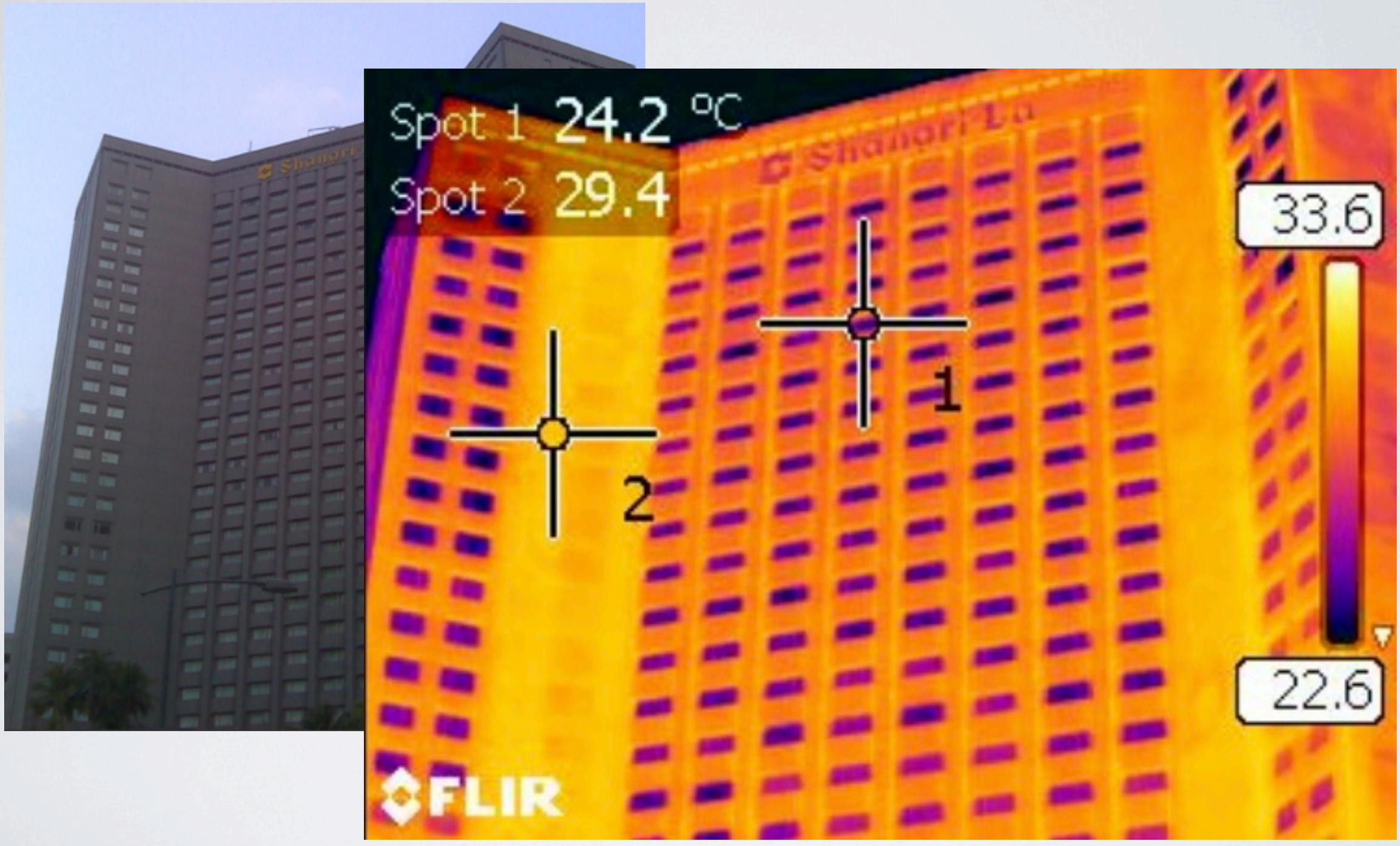
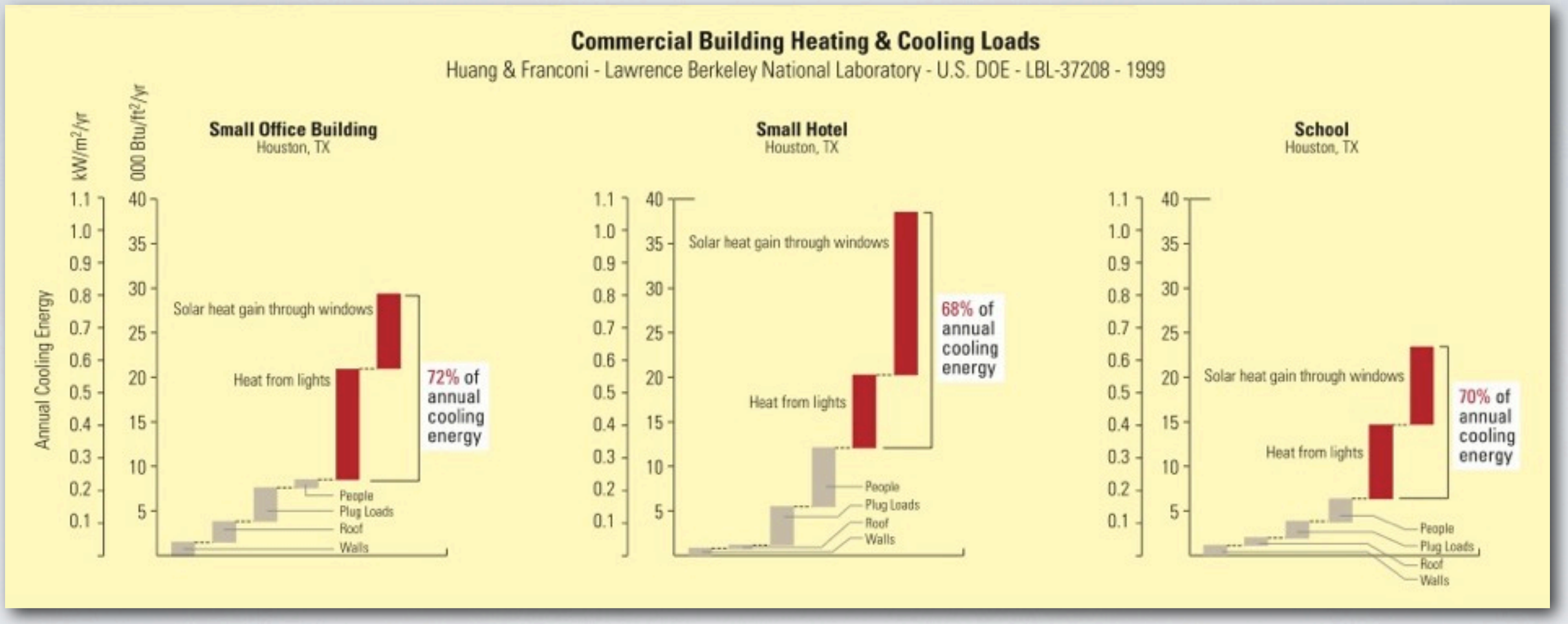
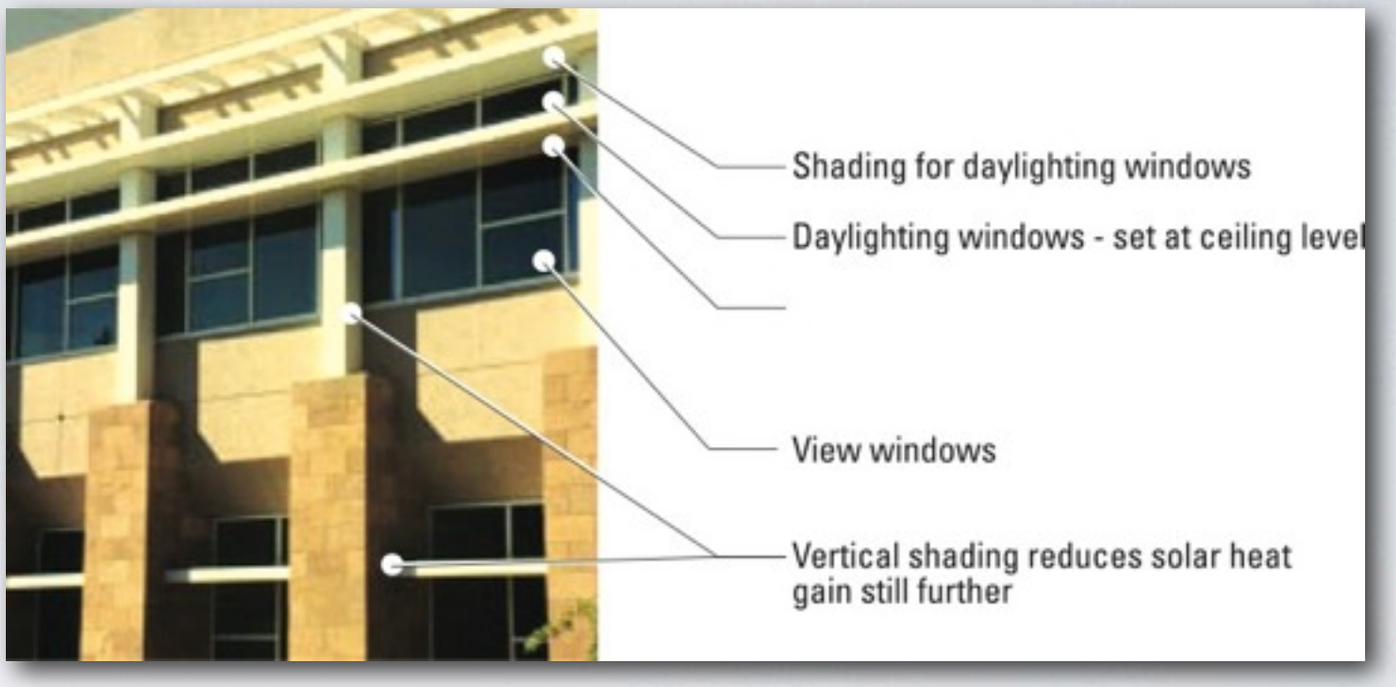


# HVAC cooling loads in commercial buildings depend on the architect's glazing decisions

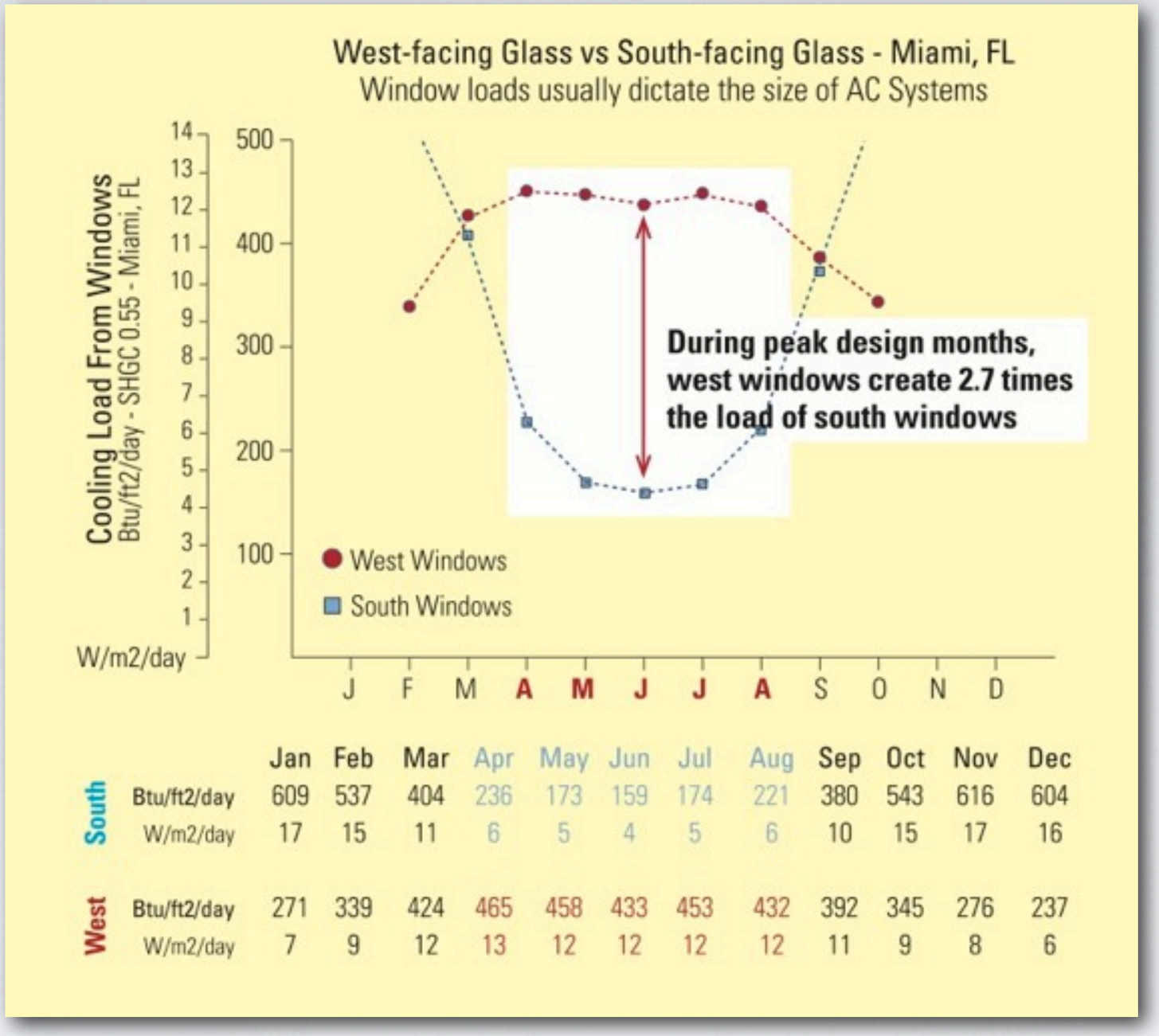


# Even better than shading... Design for daylighting





# West-facing glass dictates the size of the cooling equipment (It governs the PEAK cooling load)




| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South | Btu/ft2/day | 609 | 537 | 404 | 236 | 173 | 159 | 174 | 221 | 380 | 543 | 616 | 604 |
| | W/m2/day | 17 | 15 | 11 | 6 | 5 | 4 | 5 | 6 | 10 | 15 | 17 | 16 |
| West | Btu/ft2/day | 271 | 339 | 424 | 465 | 458 | 433 | 453 | 432 | 392 | 345 | 276 | 237 |
| | W/m2/day | 7 | 9 | 12 | 13 | 12 | 12 | 12 | 12 | 11 | 9 | 8 | 6 |

# If glass cannot be avoided—shade it



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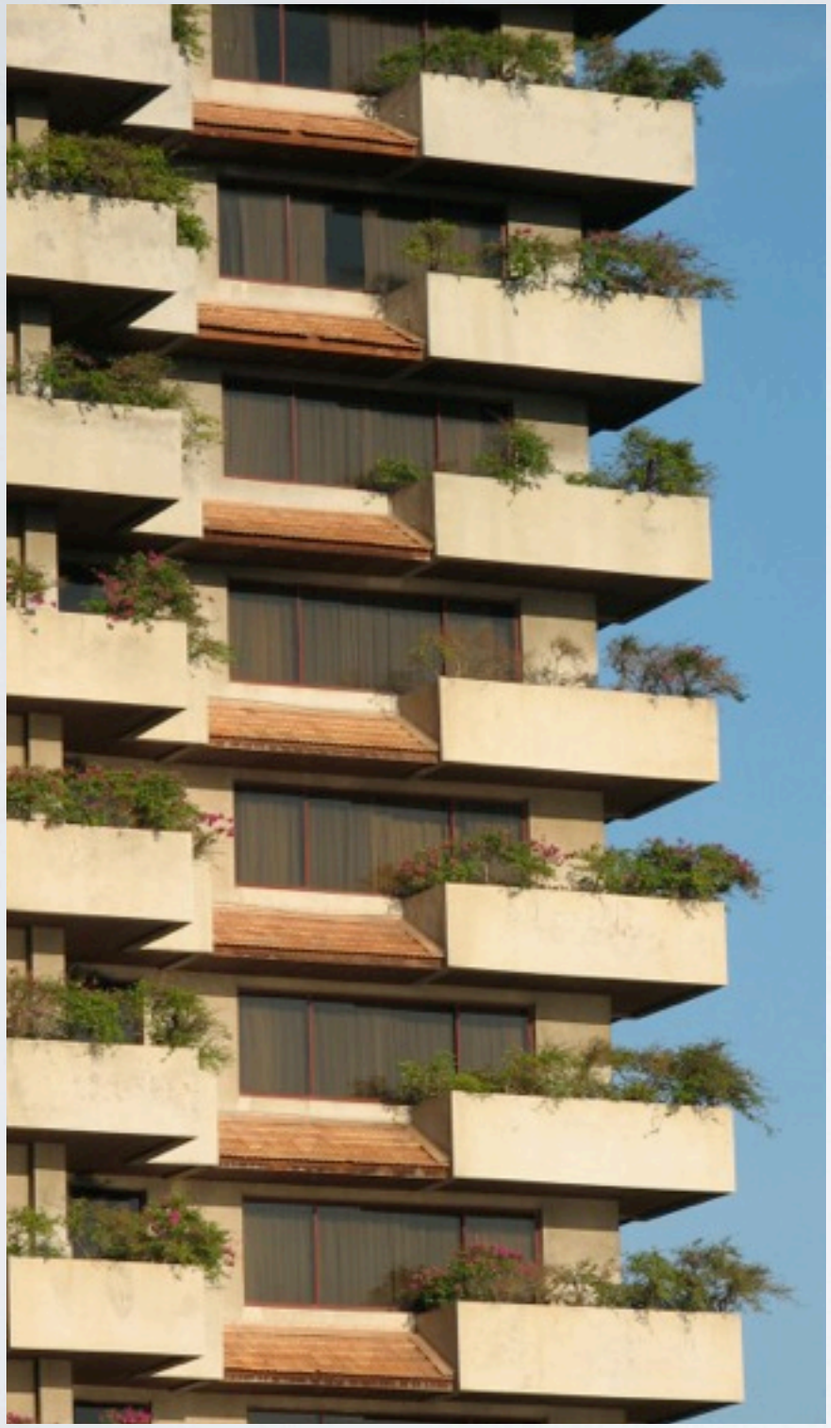



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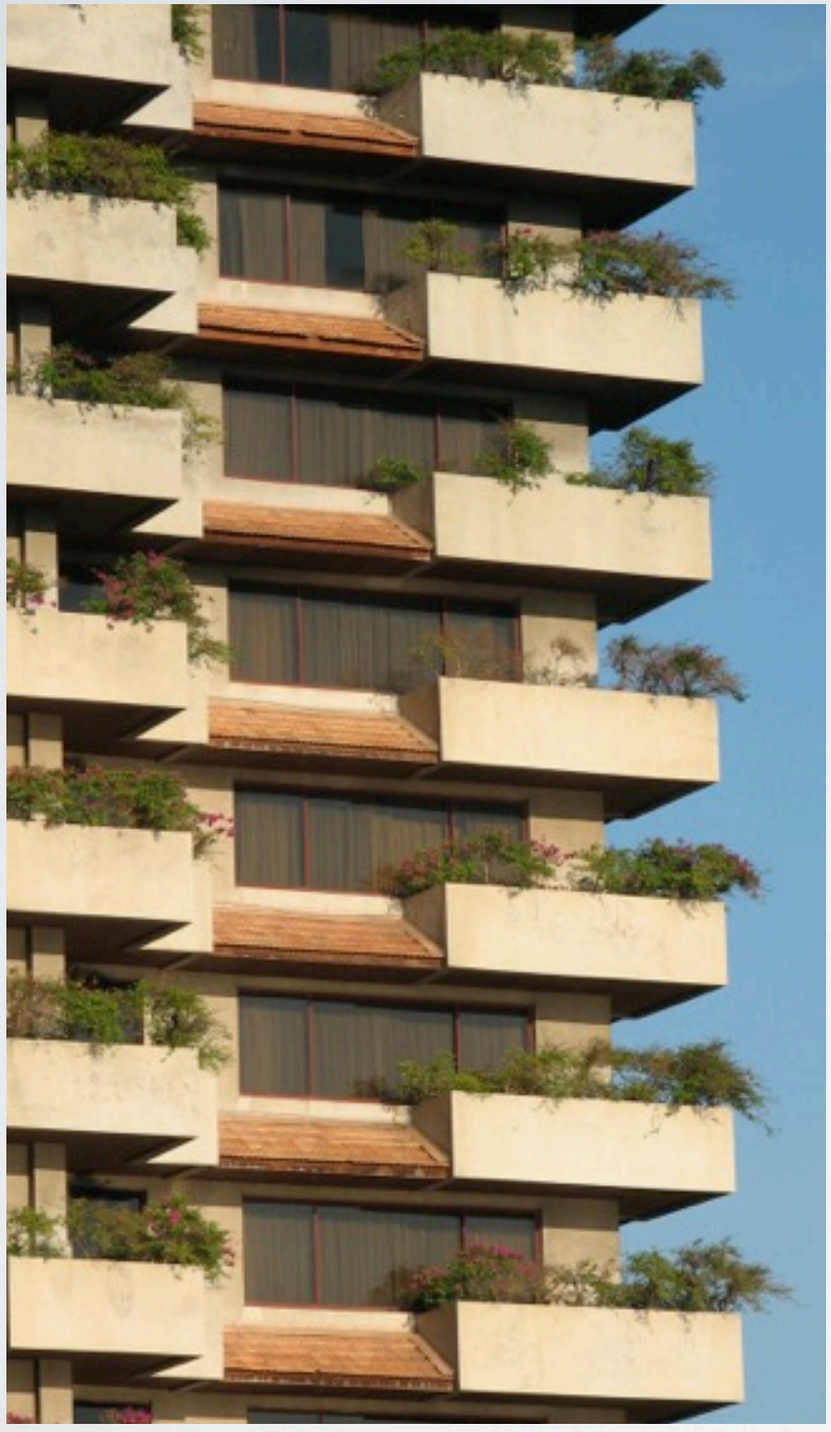



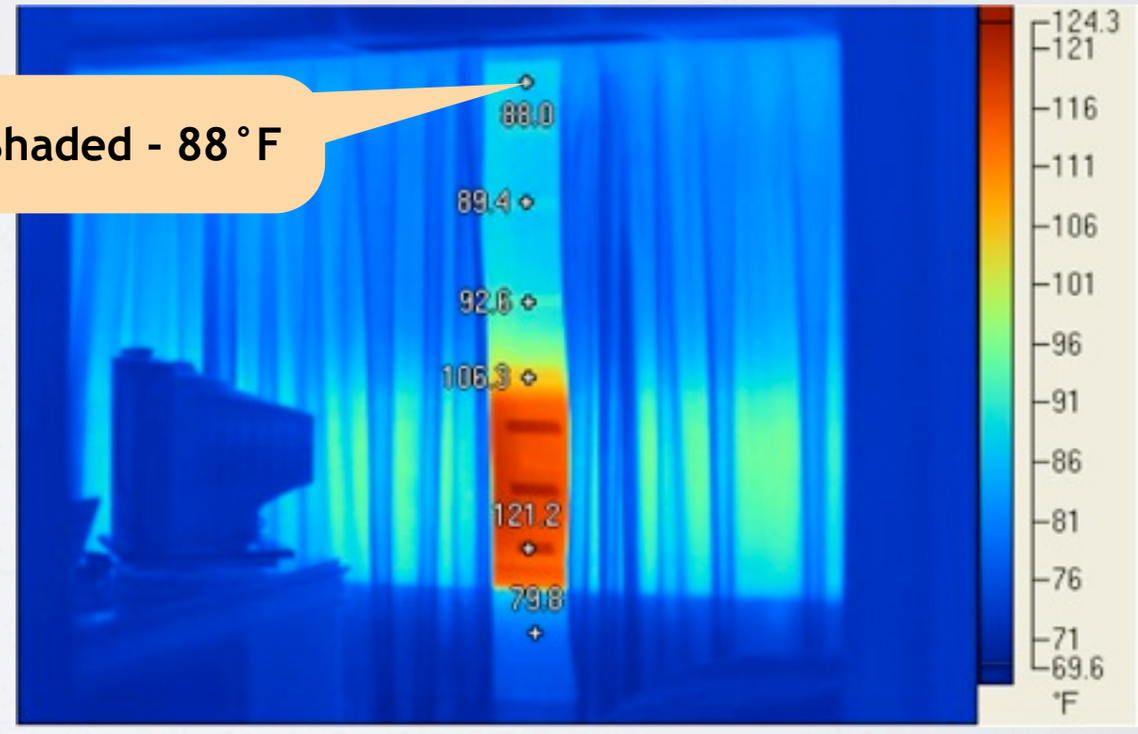

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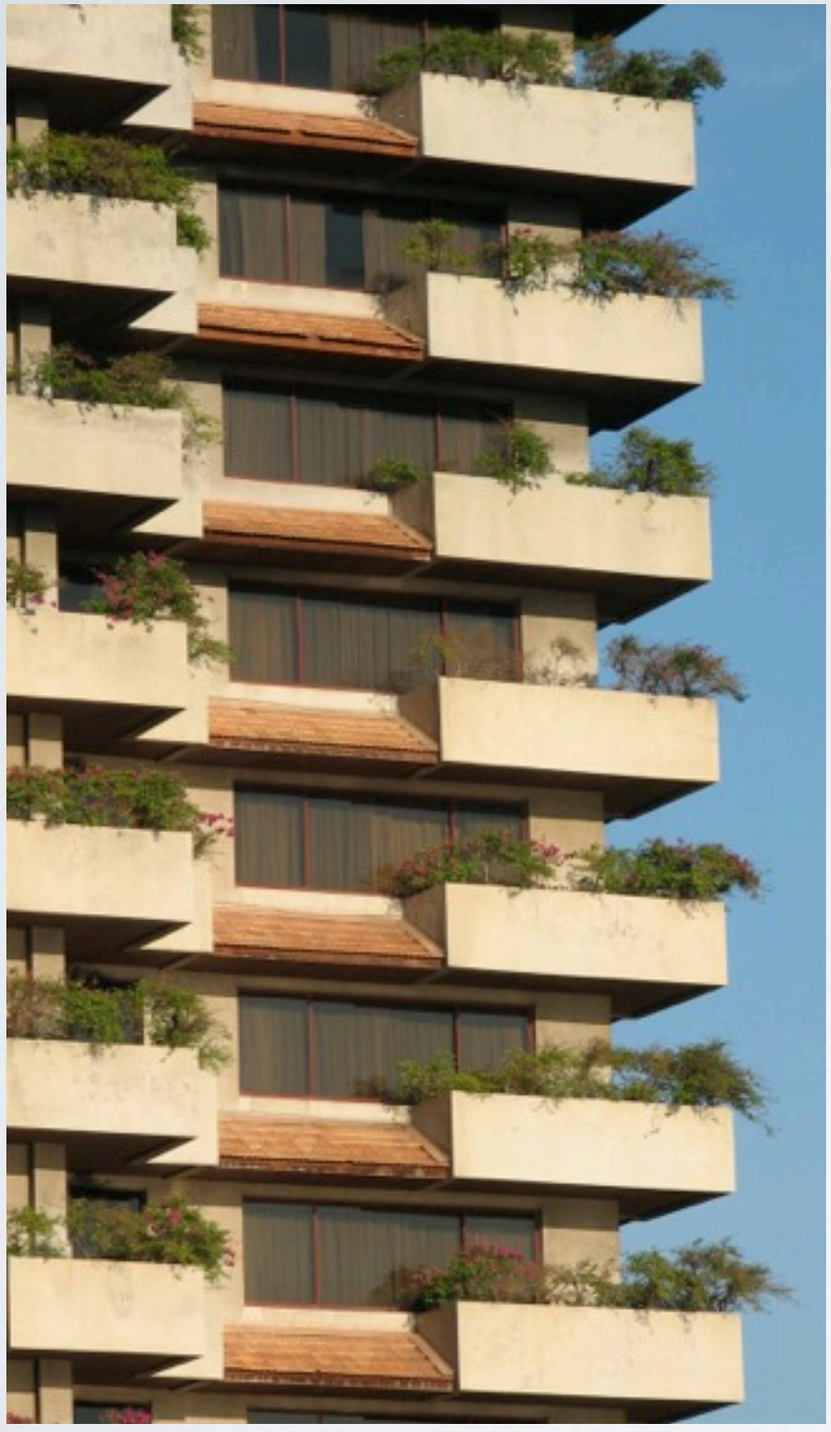
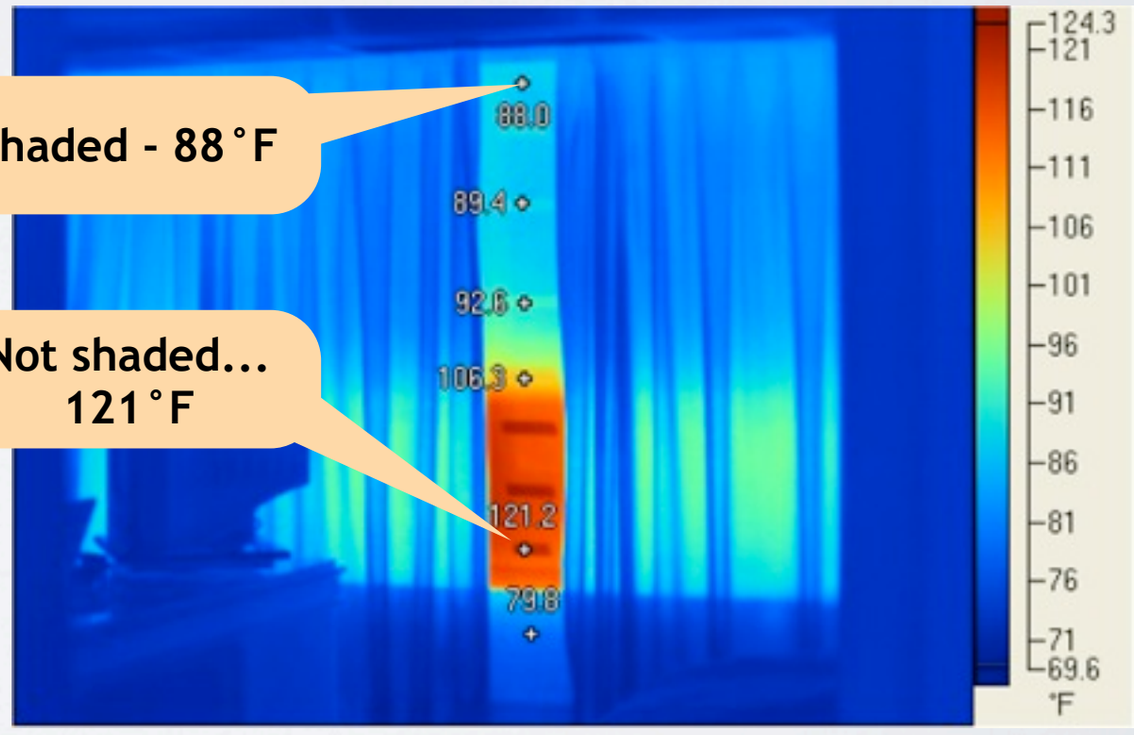
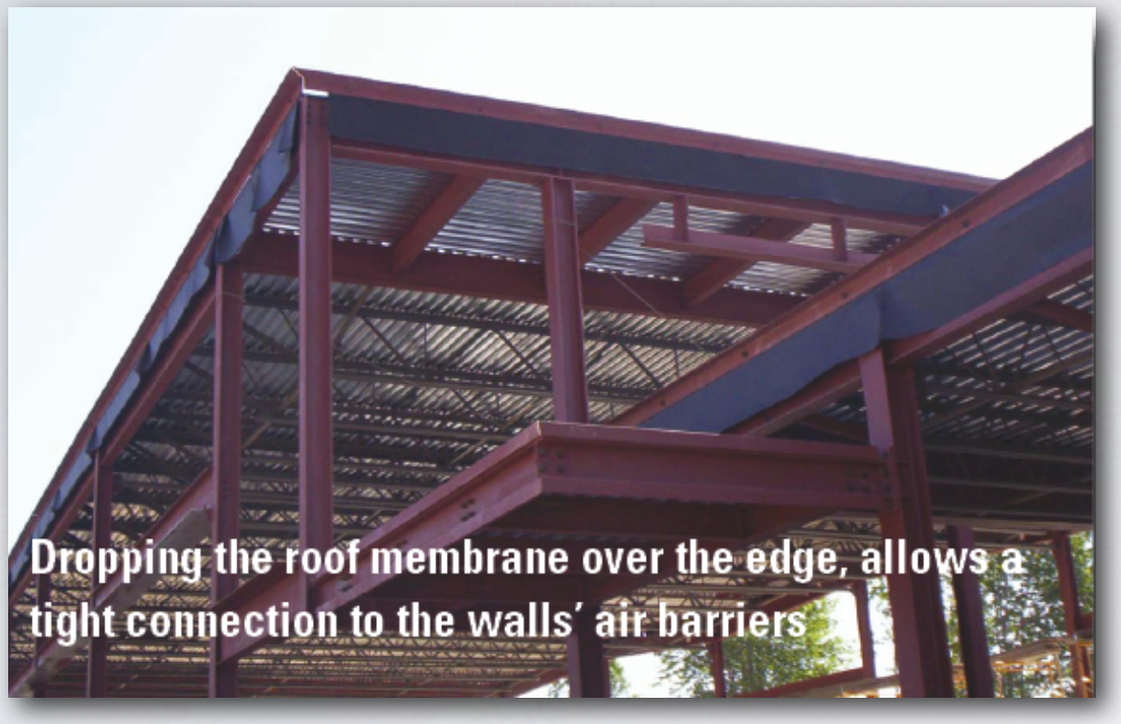


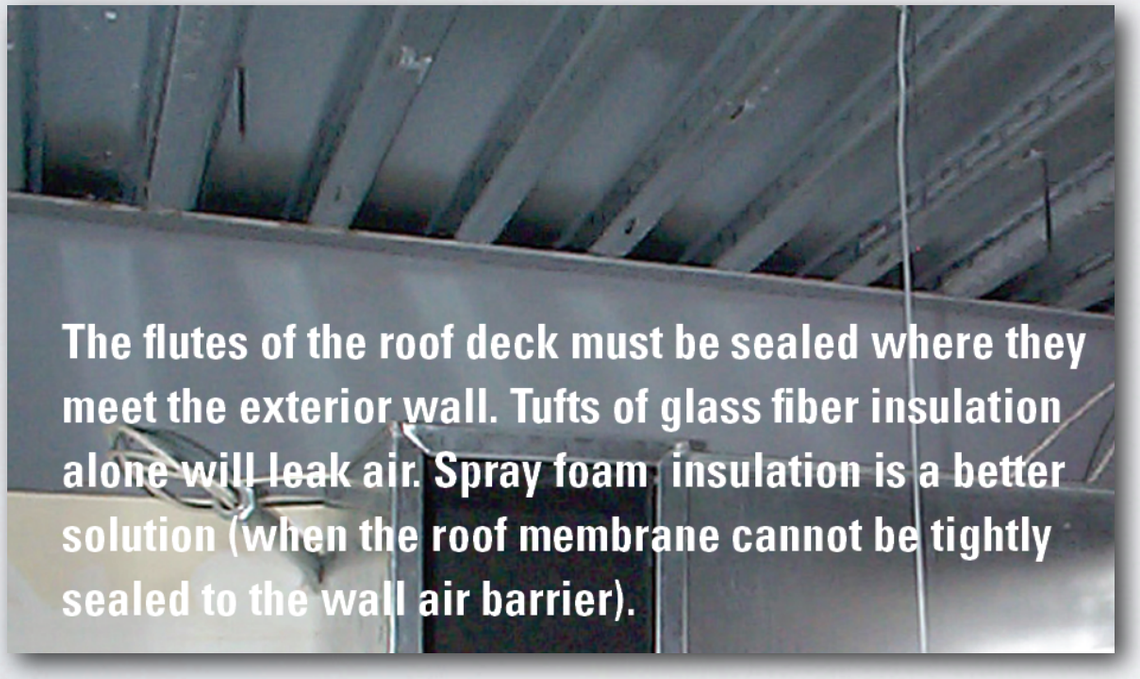




# Air-tight Buildings

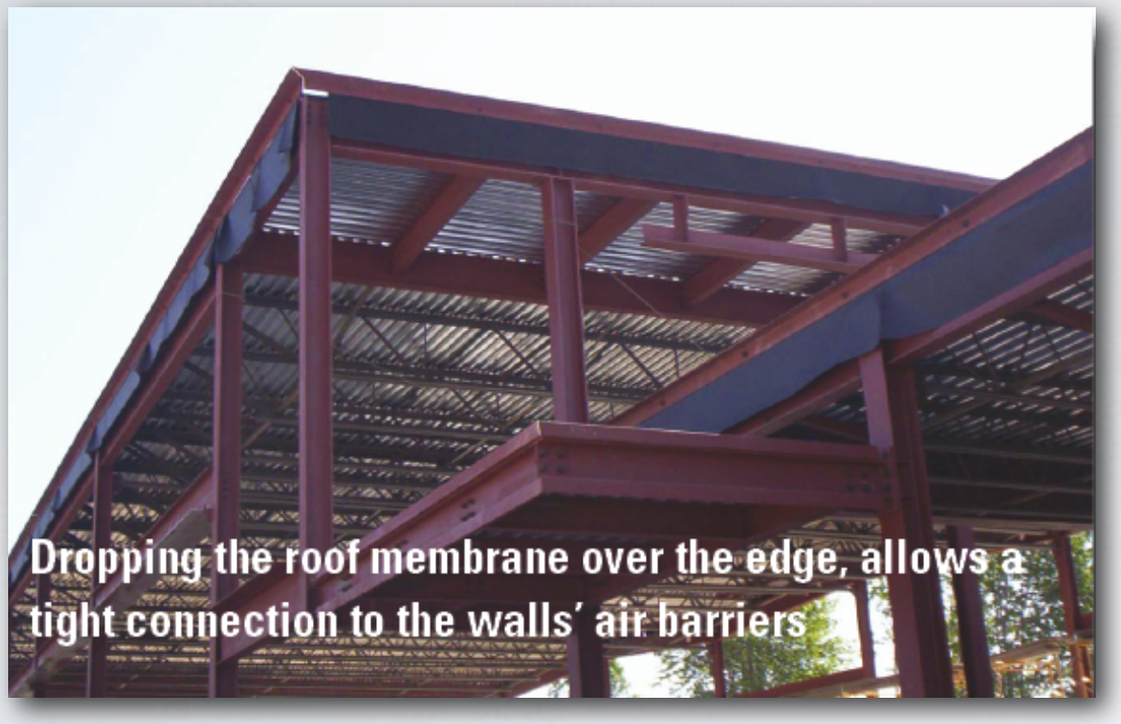


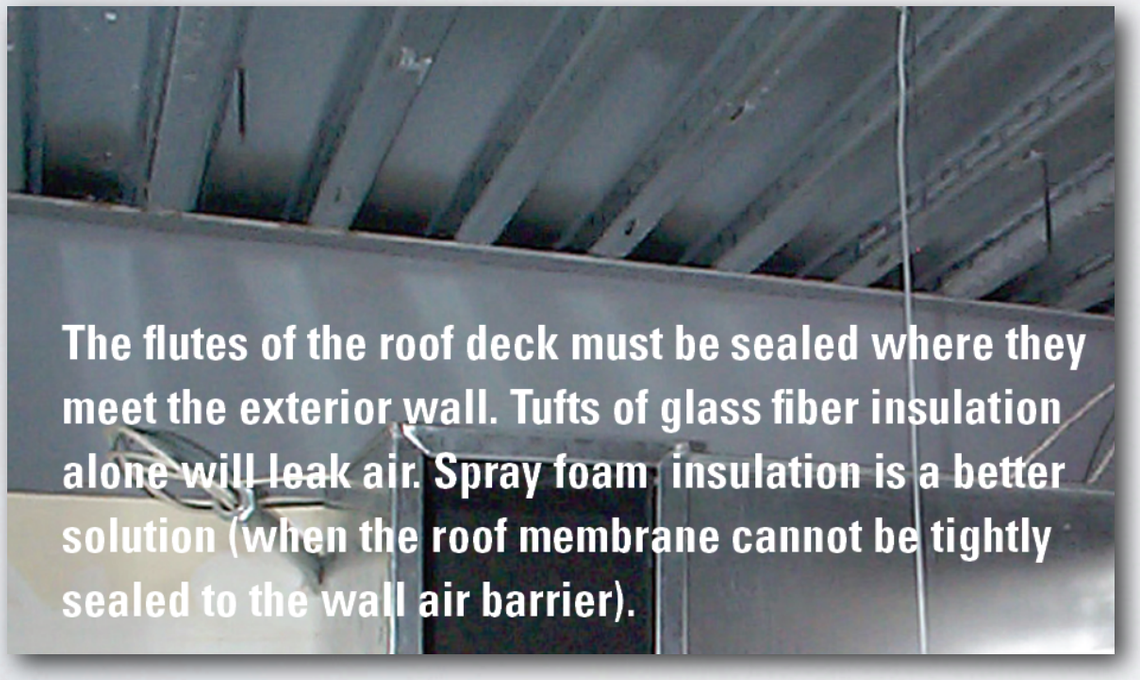
Dropping the roof membrane over the edge, allows a tight connection to the walls' air barriers

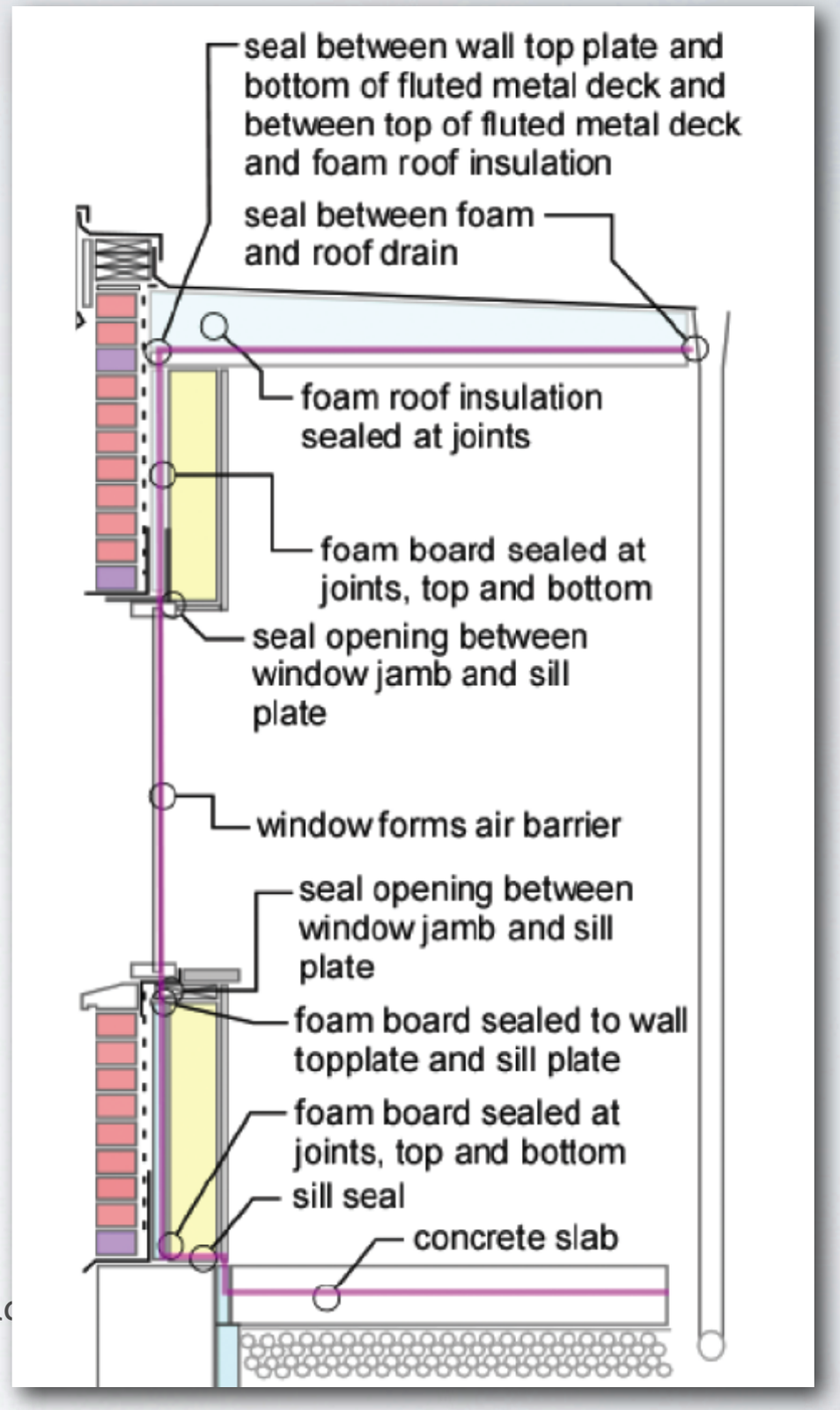


The flutes of the roof deck must be sealed where they meet the exterior wall. Tufts of glass fiber insulation alone will leak air. Spray foam insulation is a better solution (when the roof membrane cannot be tightly sealed to the wall air barrier).

# Air-tight Buildings



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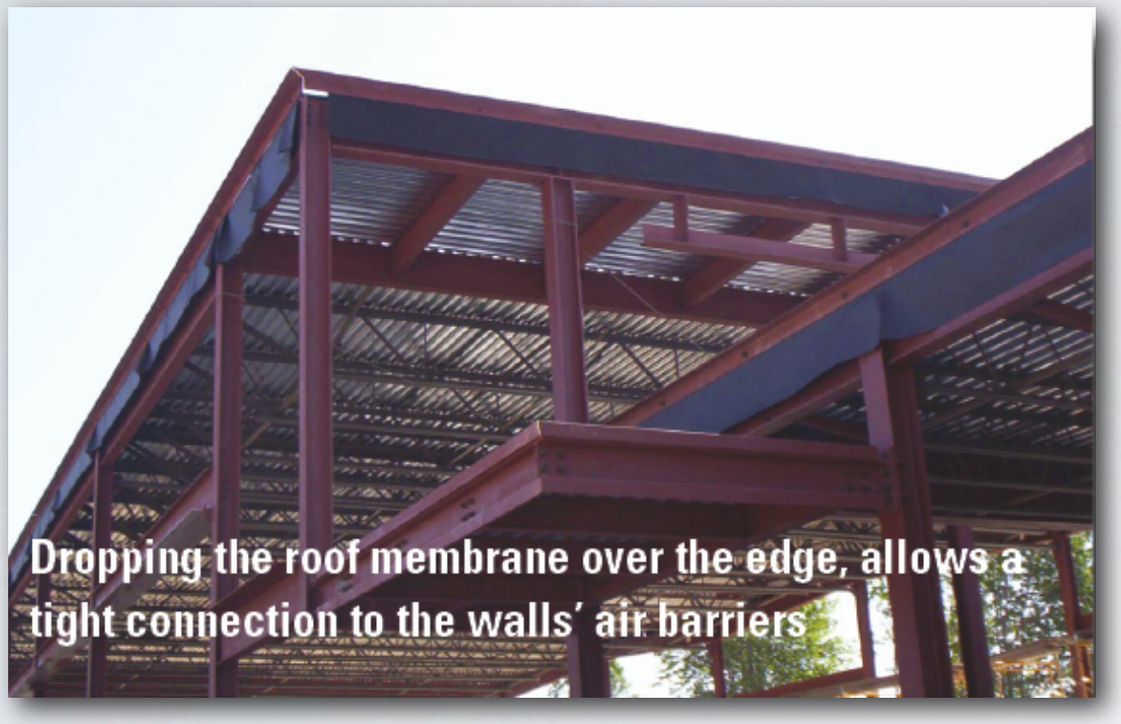
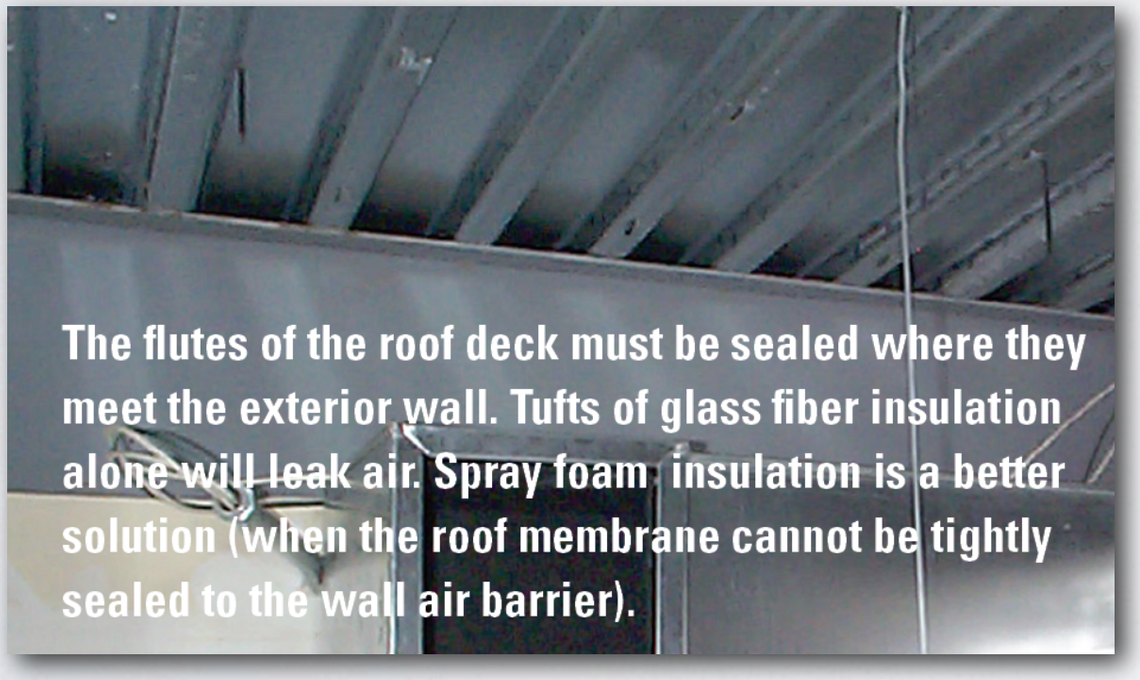
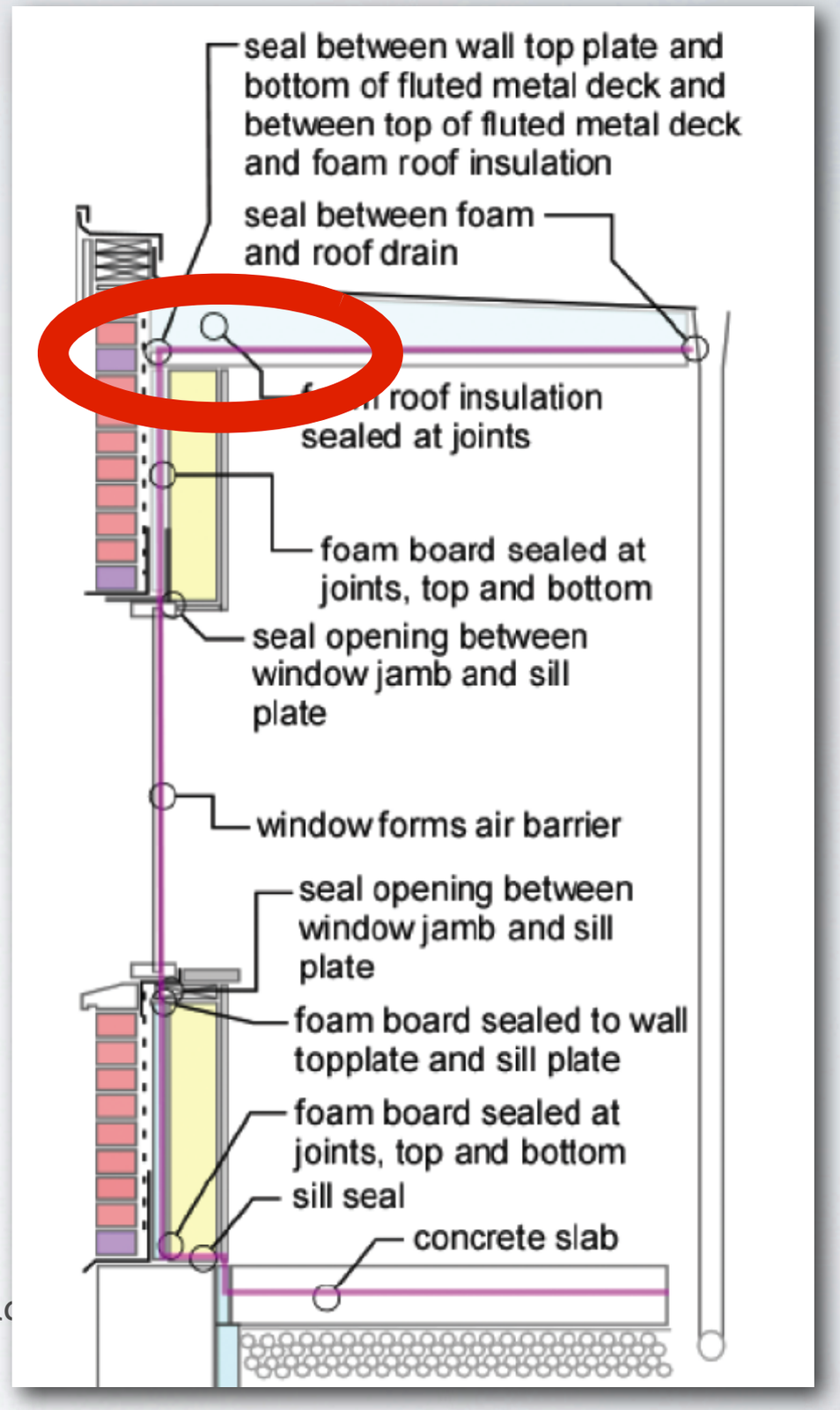


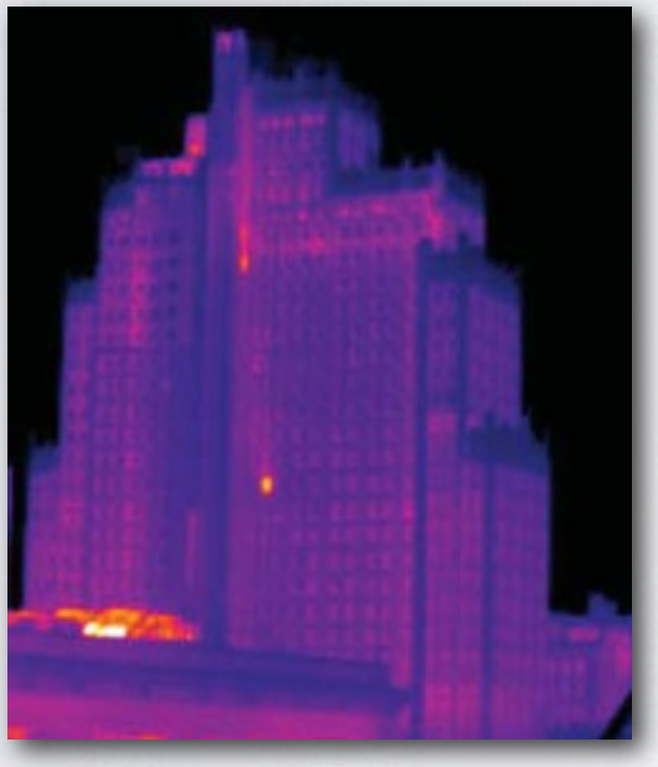



# Reason #1 - Mold prevention



# Reason #2 - Energy waste



# Reason #2 - Energy waste



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**80-year-old building**
**Some air leakage**



**30-year-old building**
**Less air leakage**



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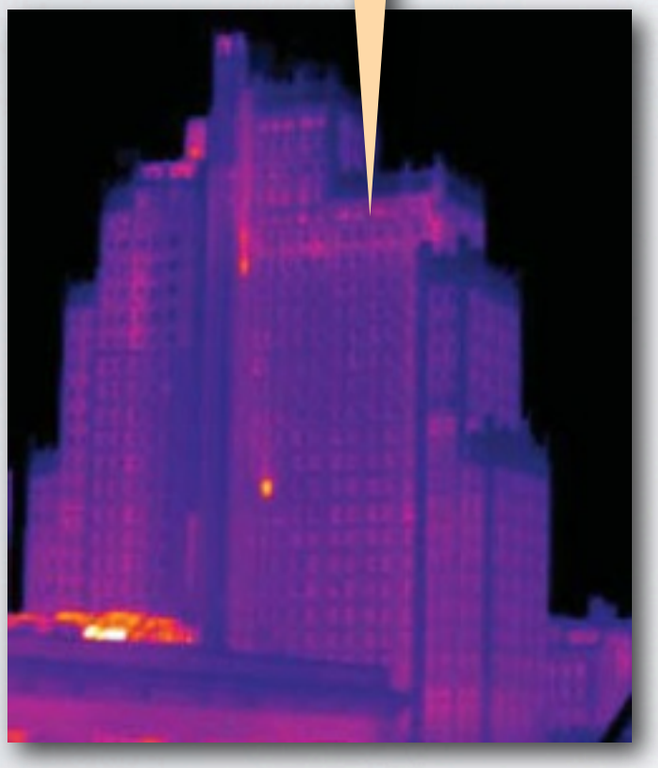
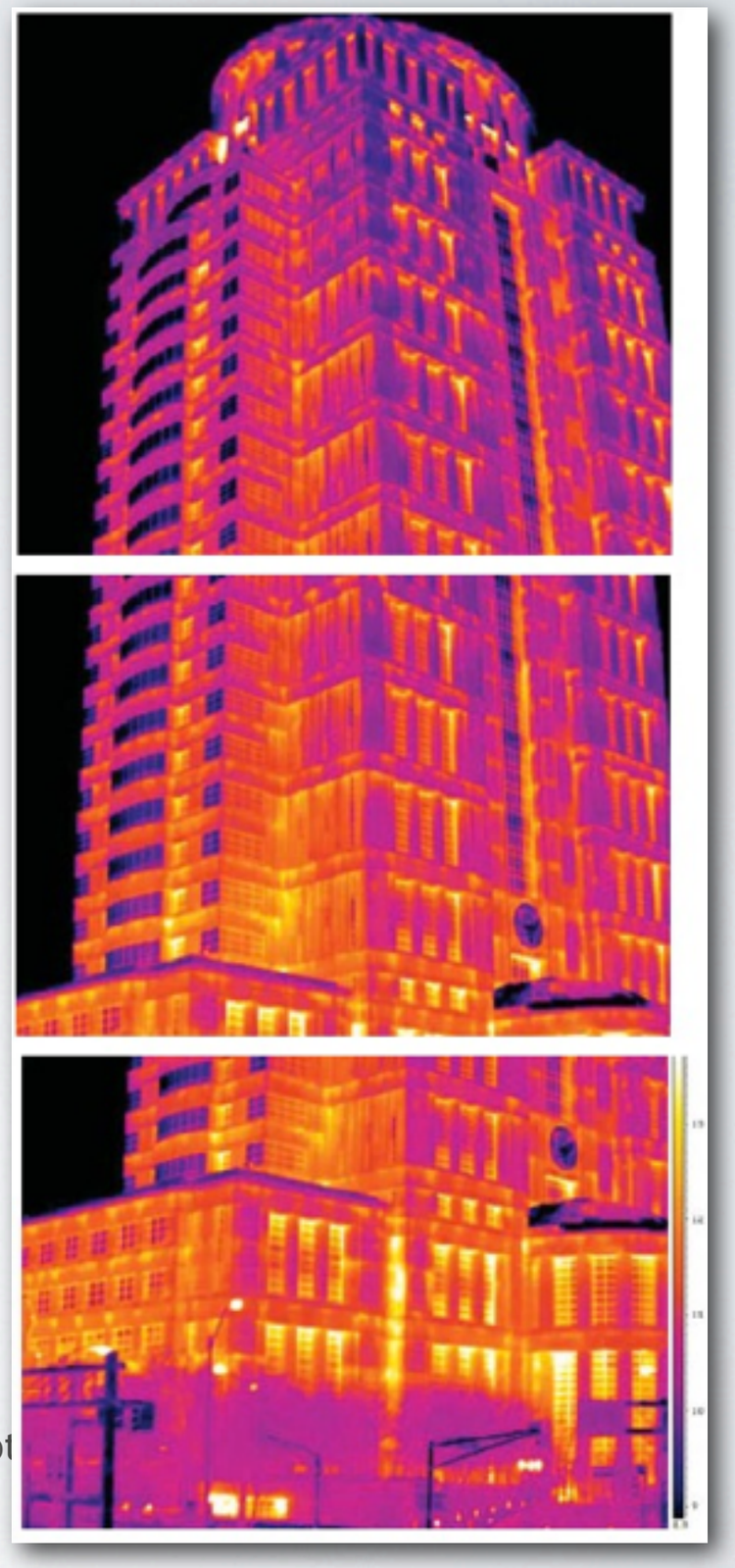


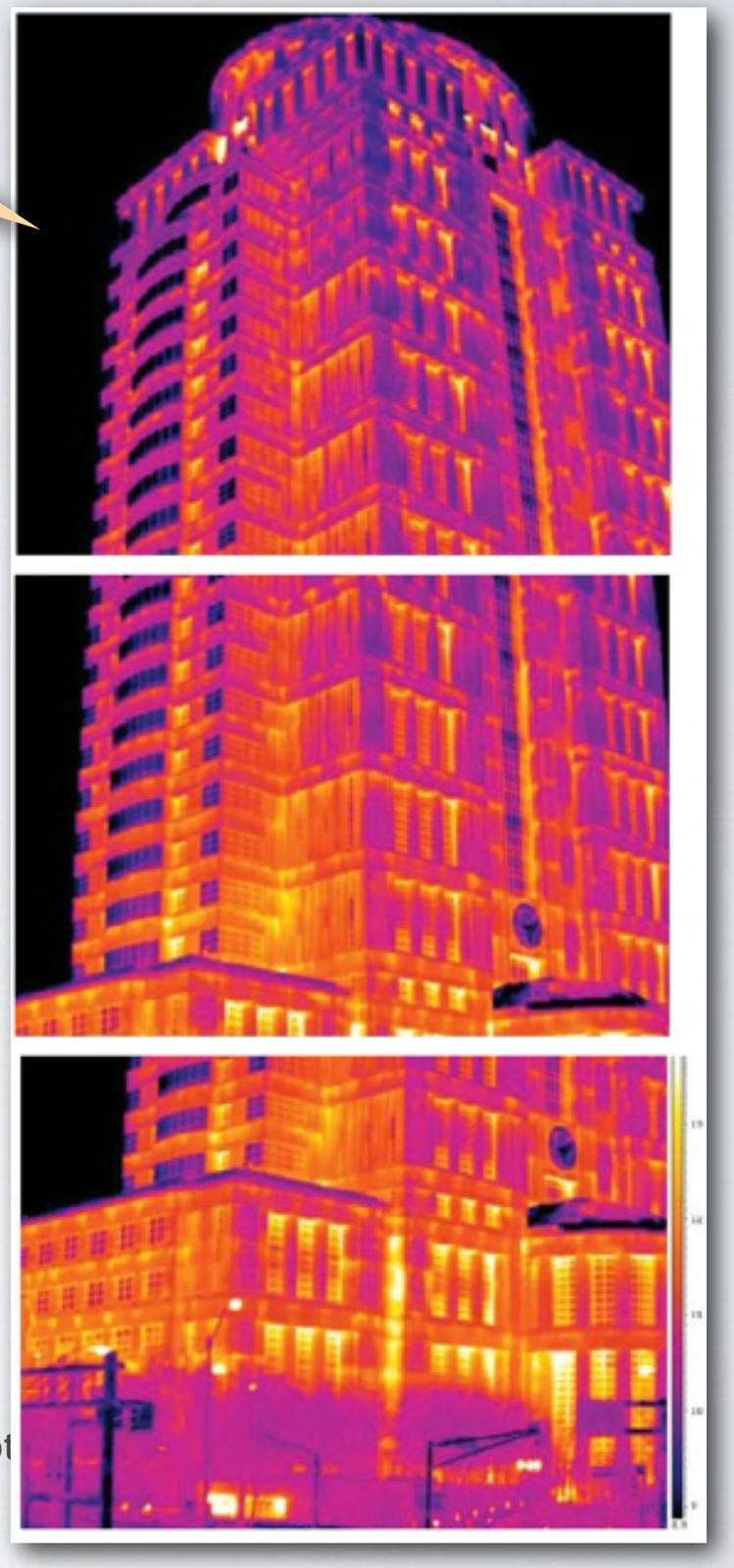
**30-year-old building**
**Less air leakage**





# Reason #2 - Energy waste

**2003 building...**
**HUGE air leakage**



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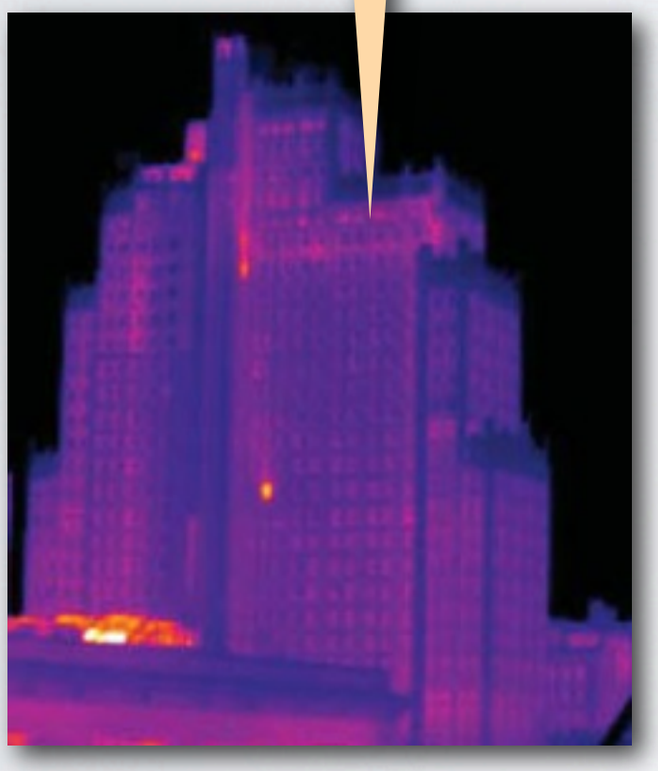

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# “Stack effect” pressure differences drive air leakage

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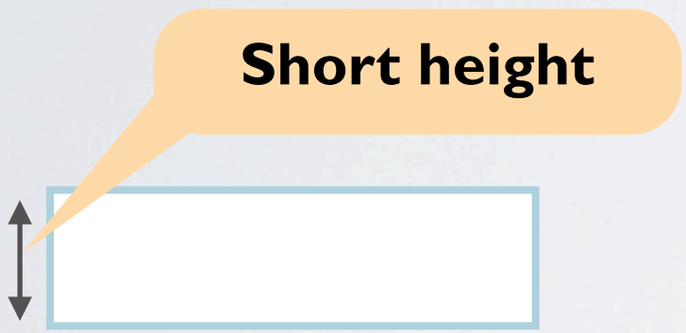

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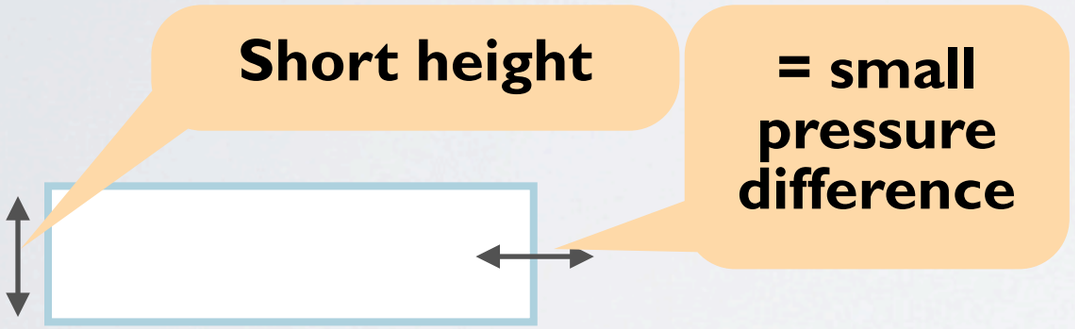

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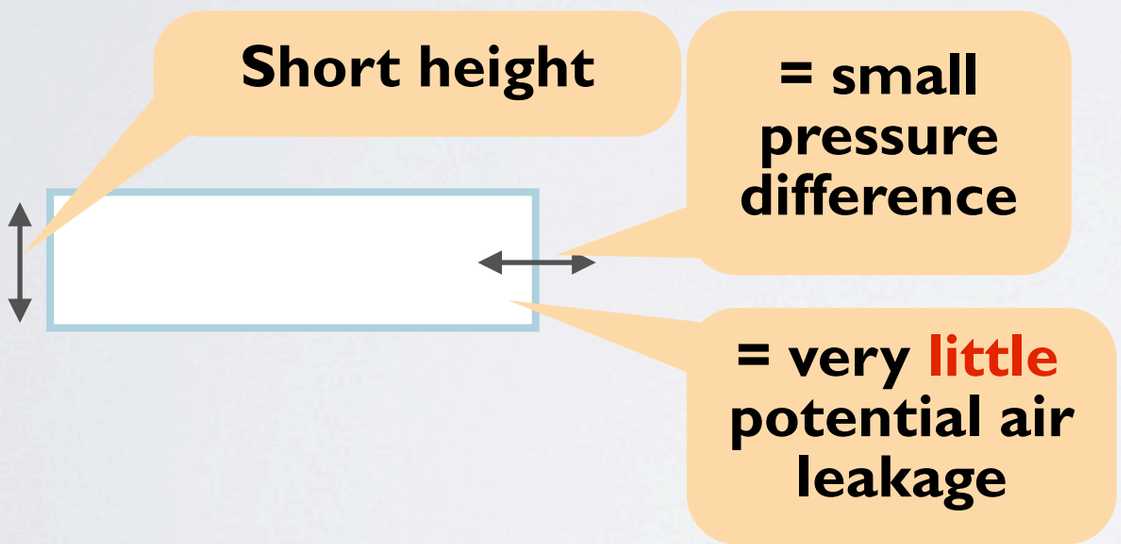

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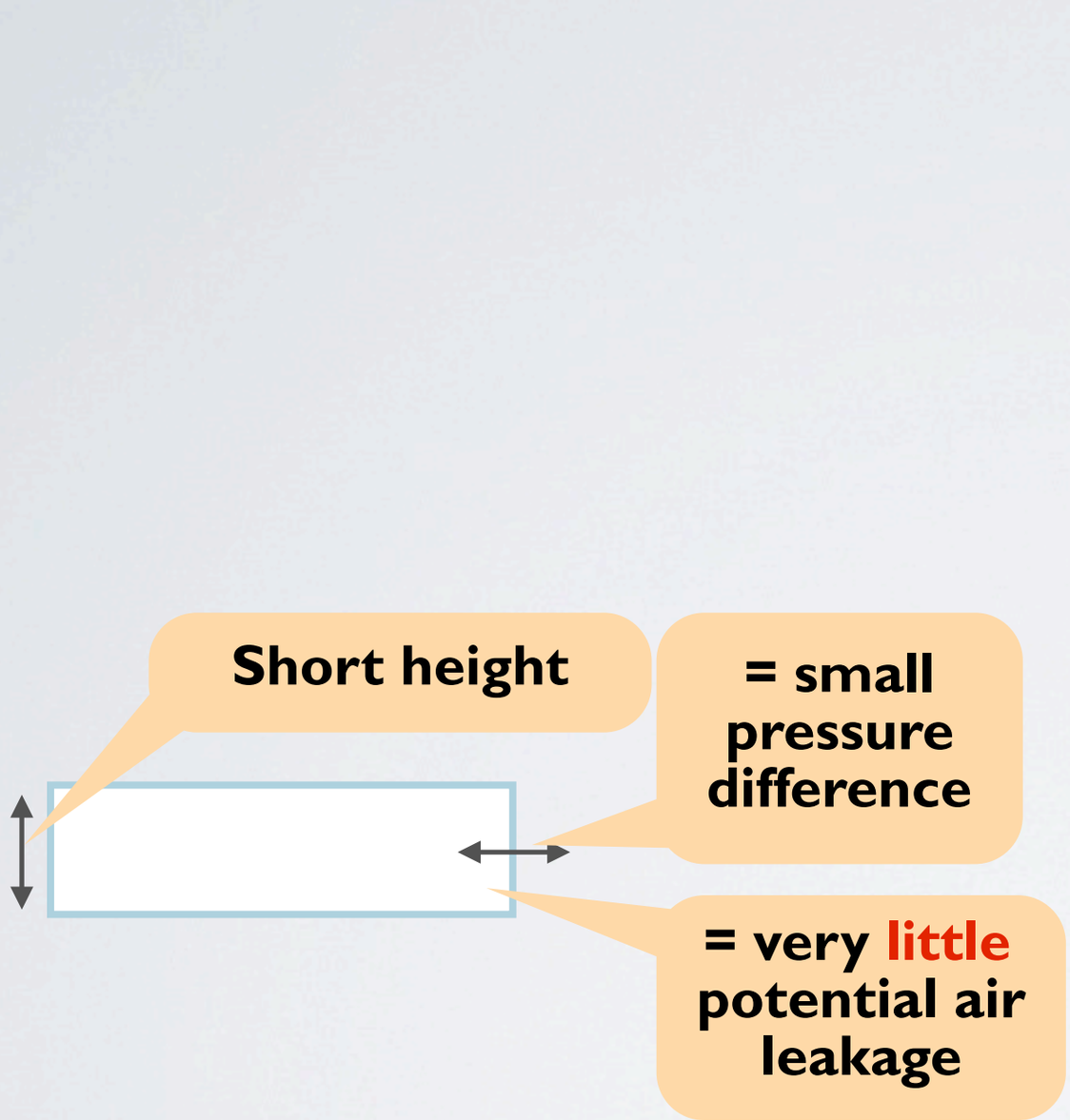

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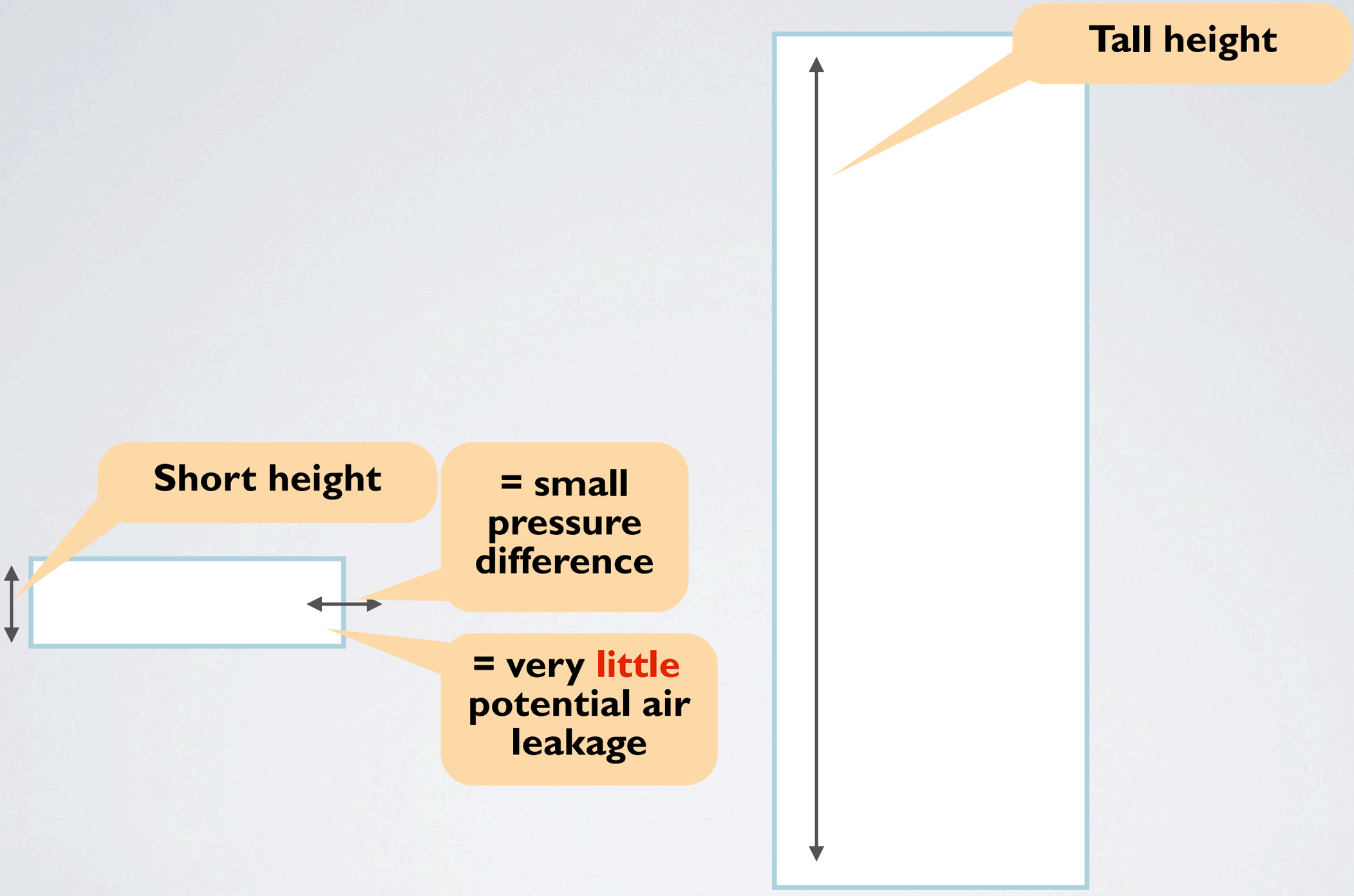

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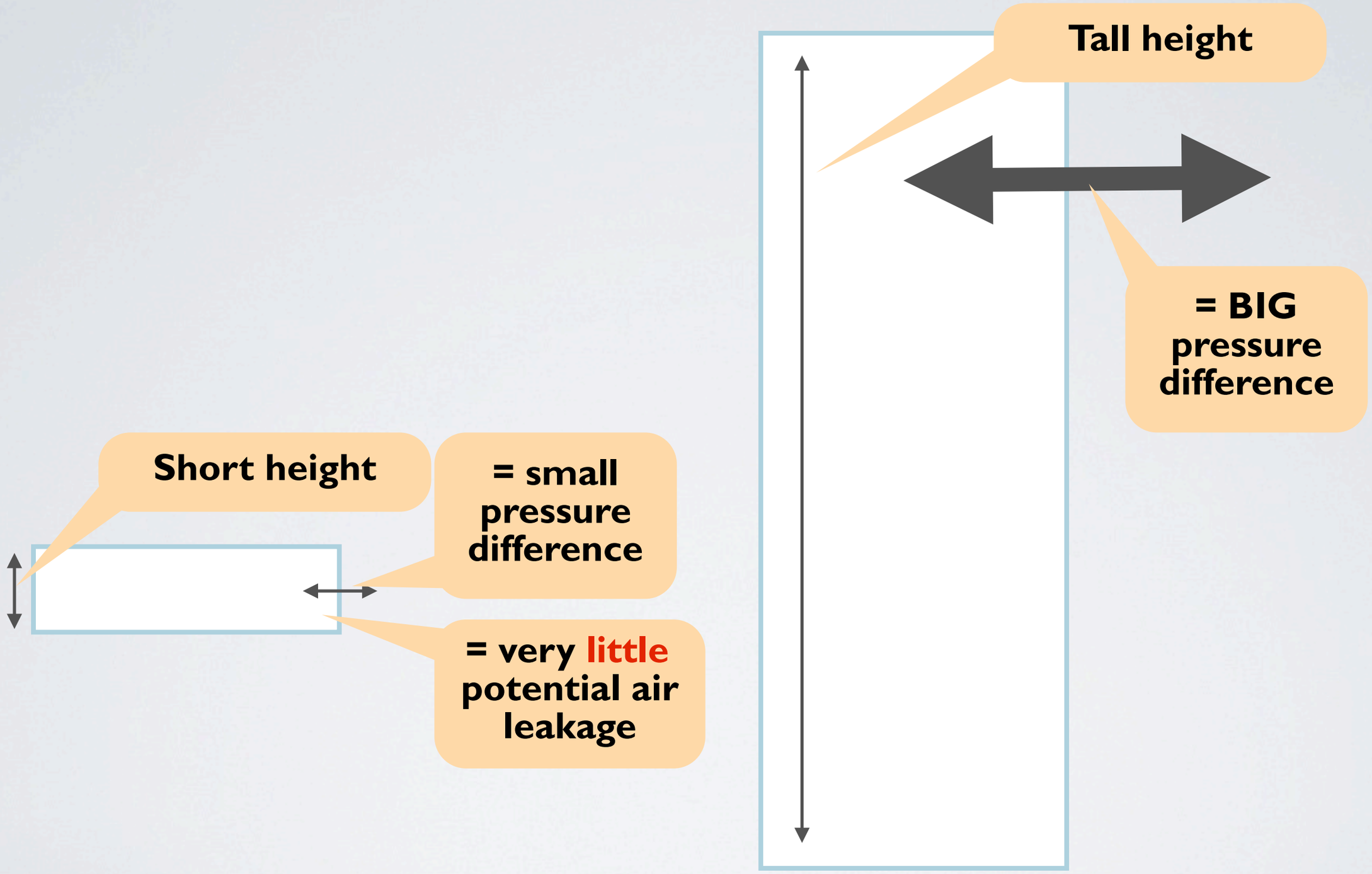

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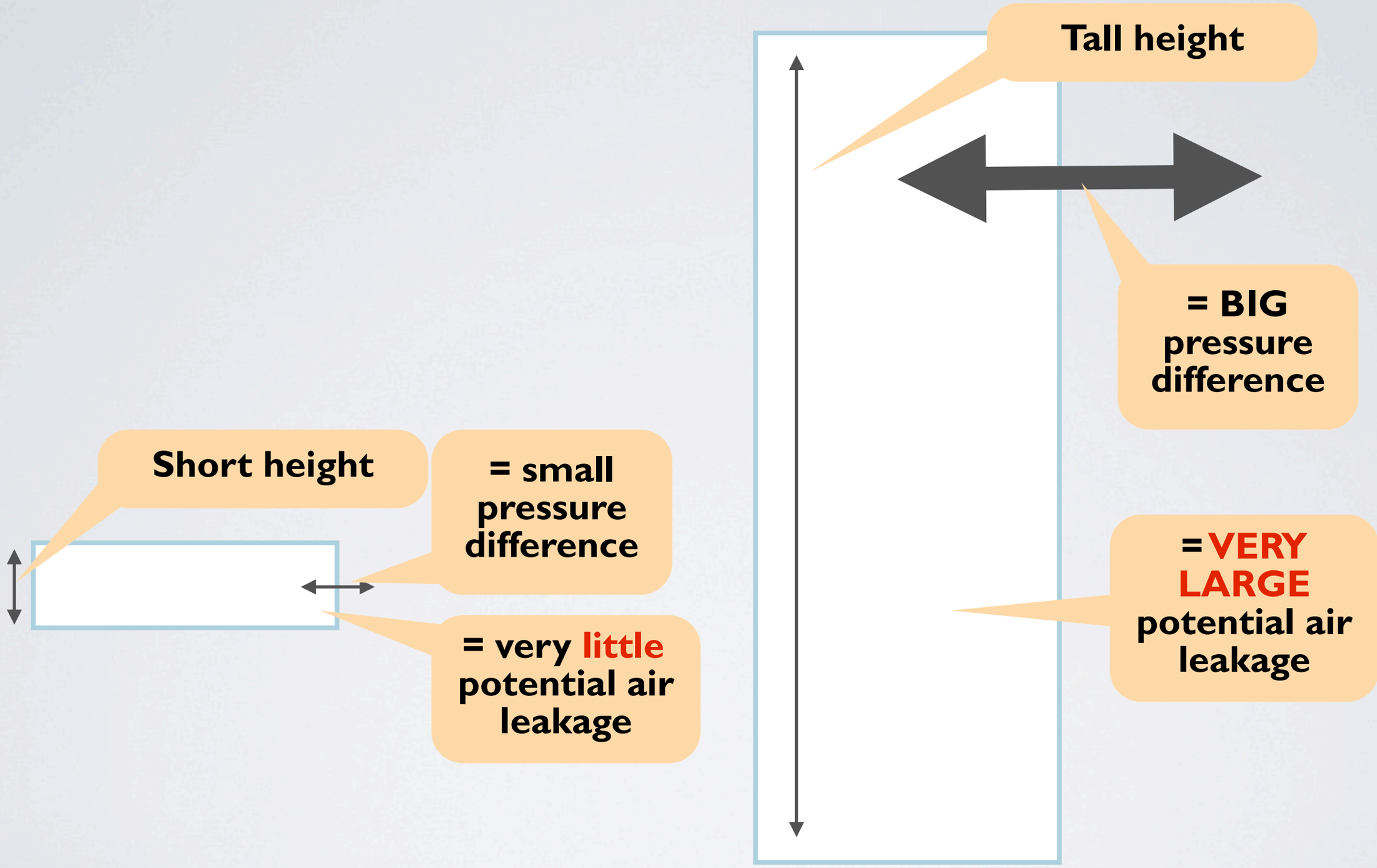
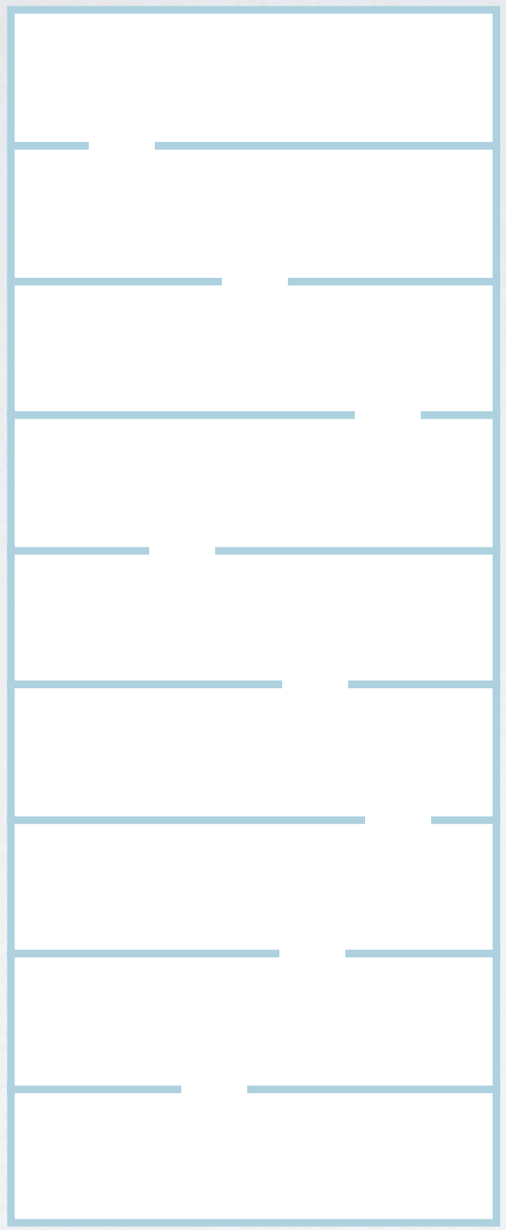


# Cold climate - Hot air rises, leakage enters at the bottom

Poor Building



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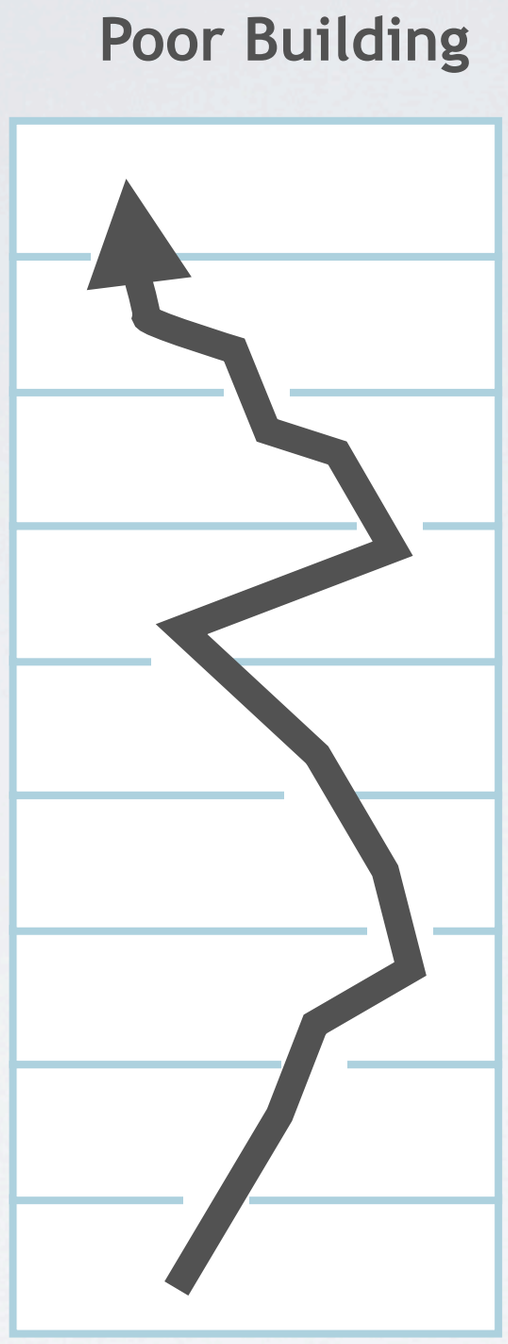

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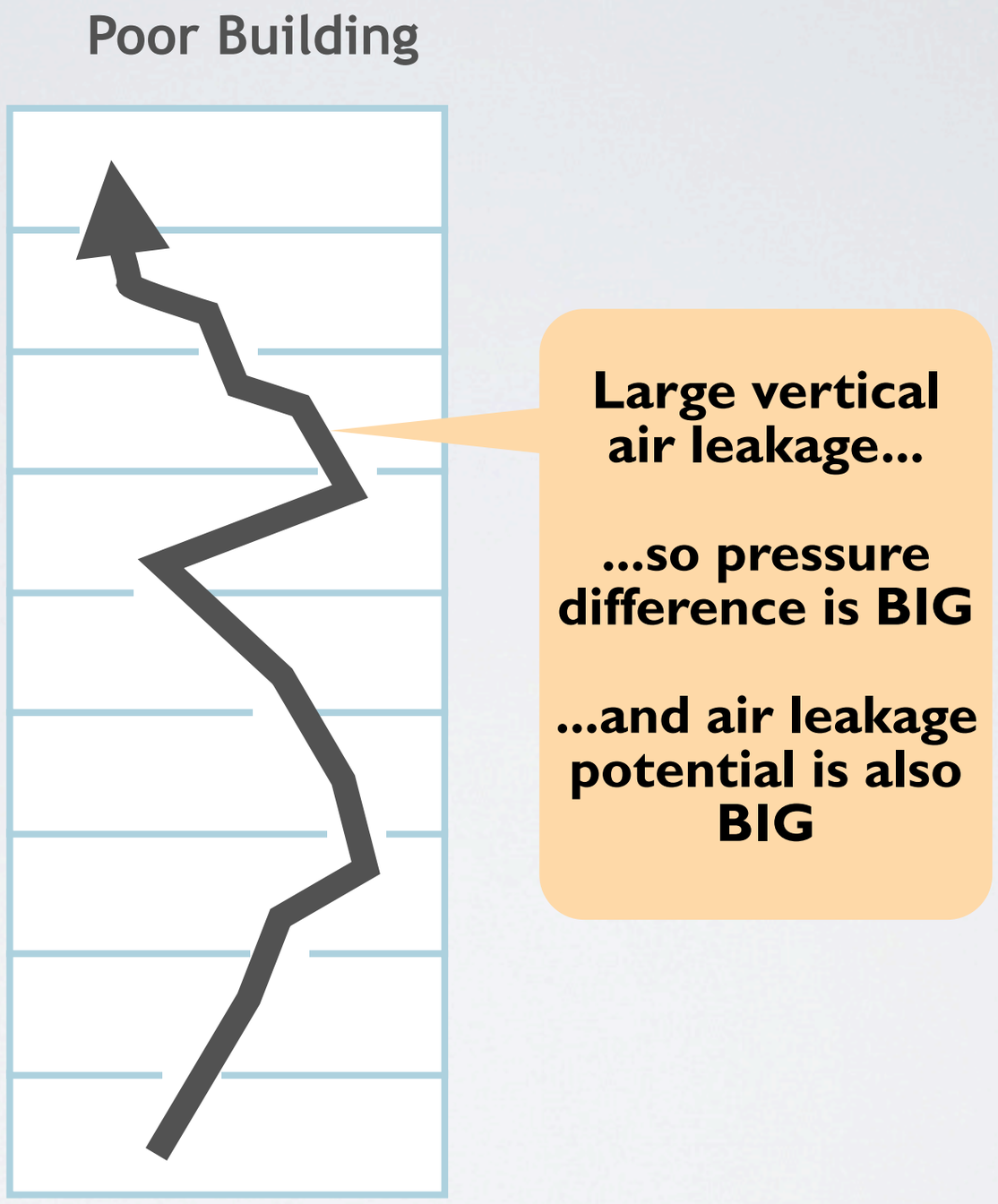

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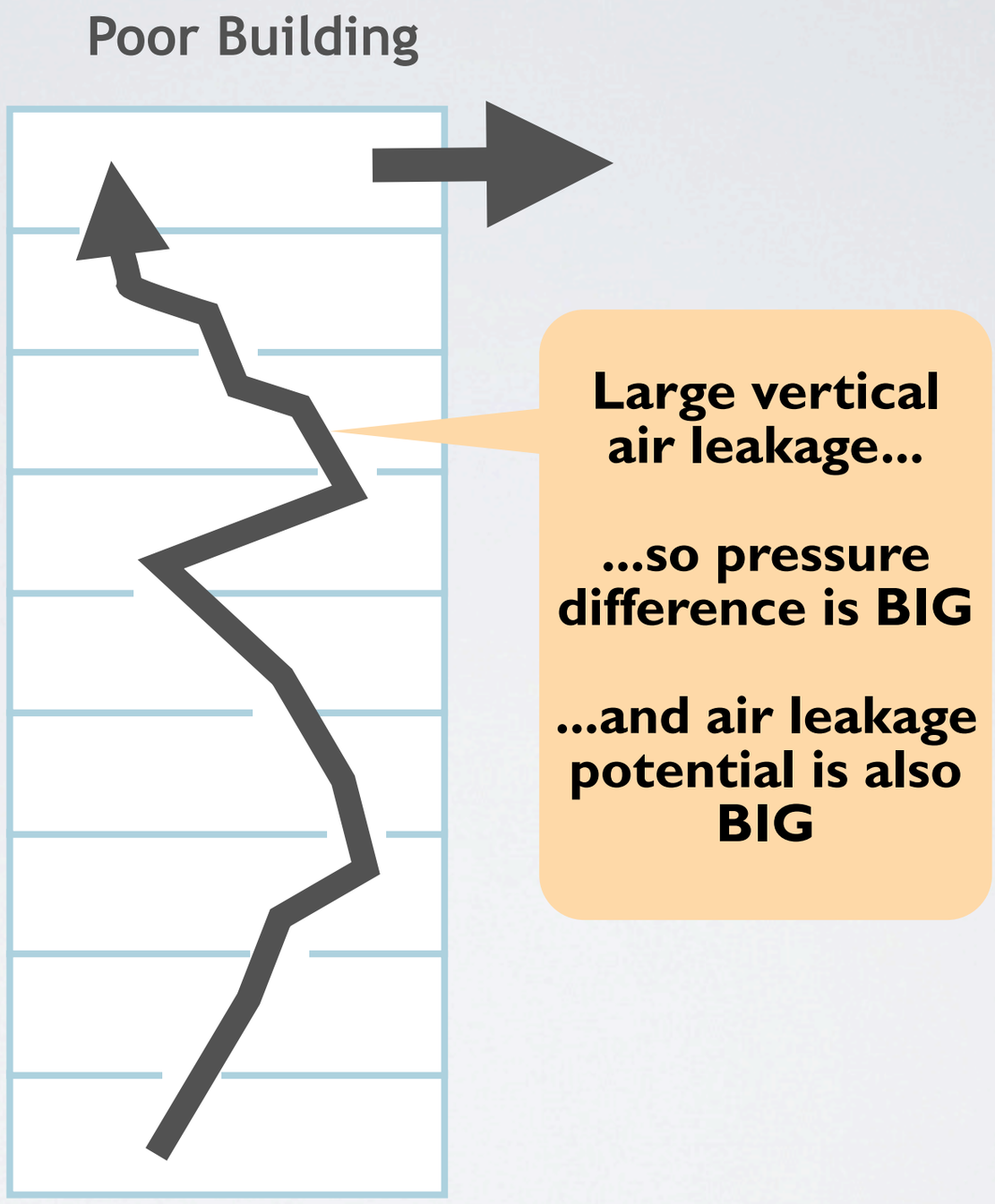

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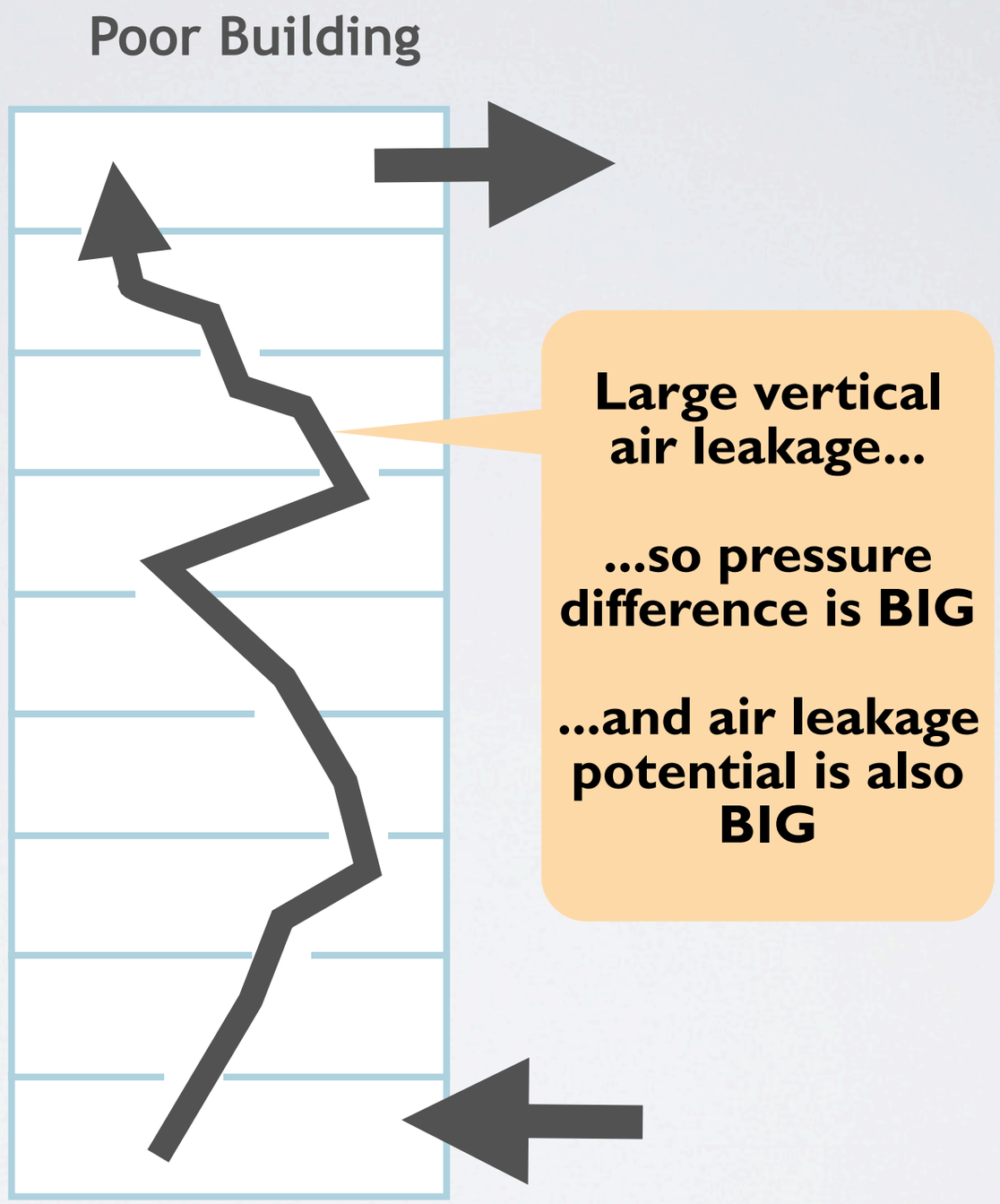

# Hot climate... stack effect is reversed. Cold air "falls out" at the bottom - Infiltration at the top, as in clinic case history

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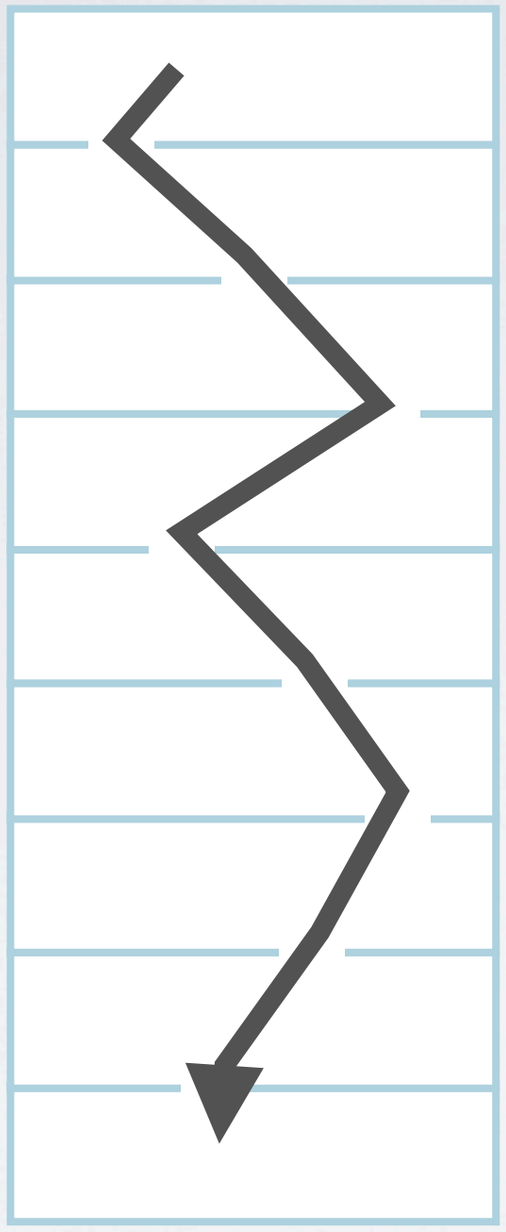

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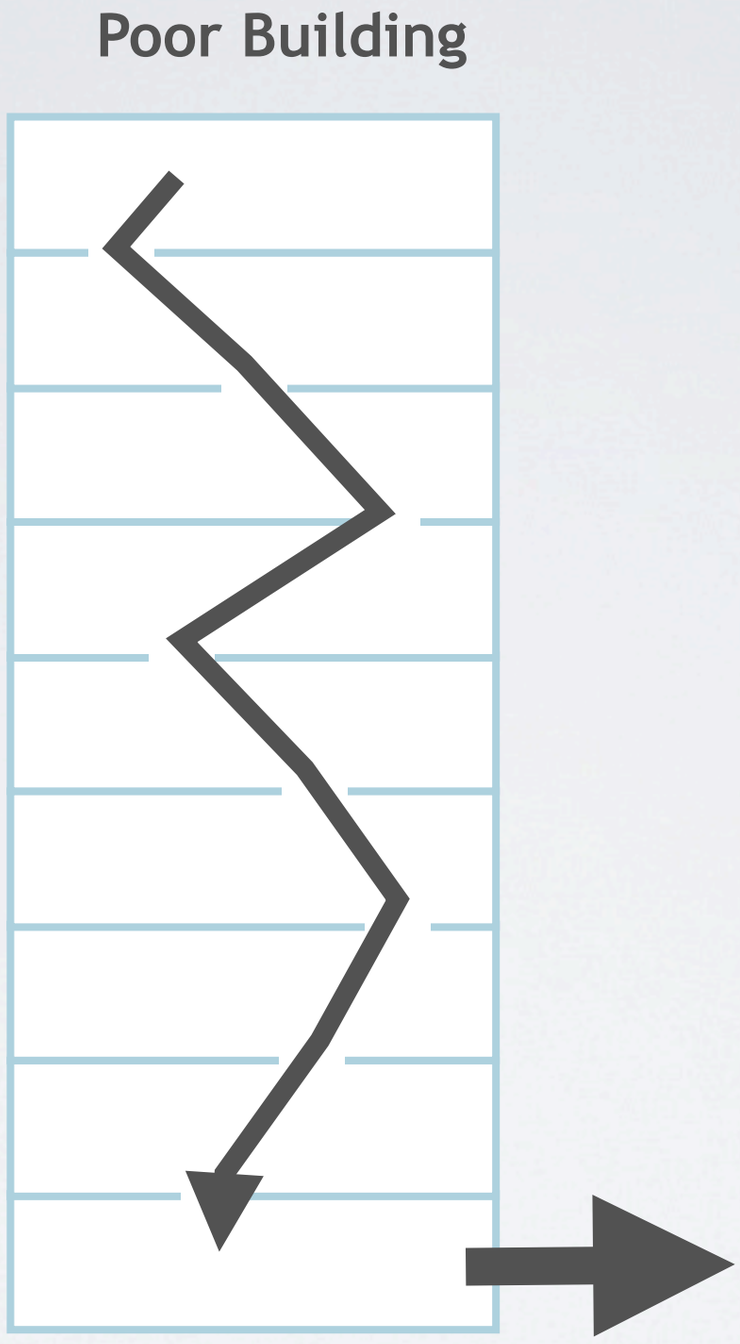

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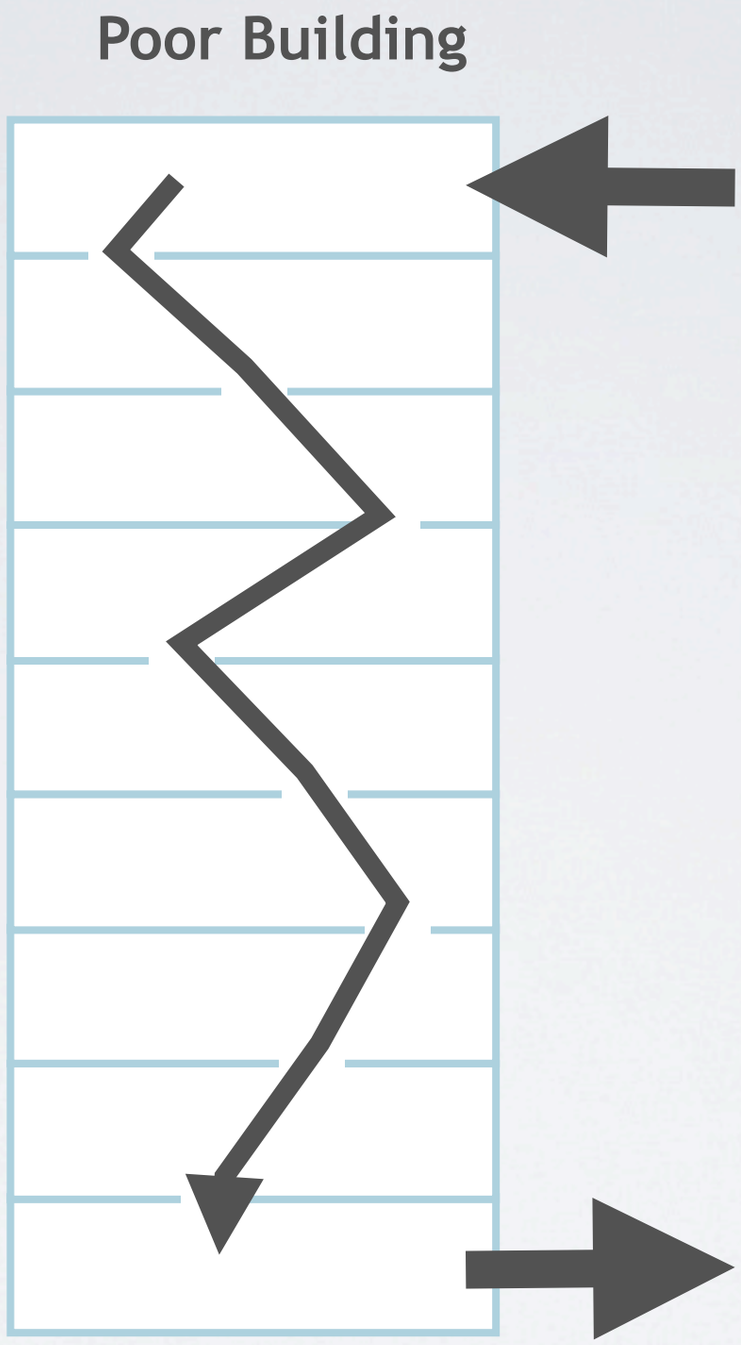

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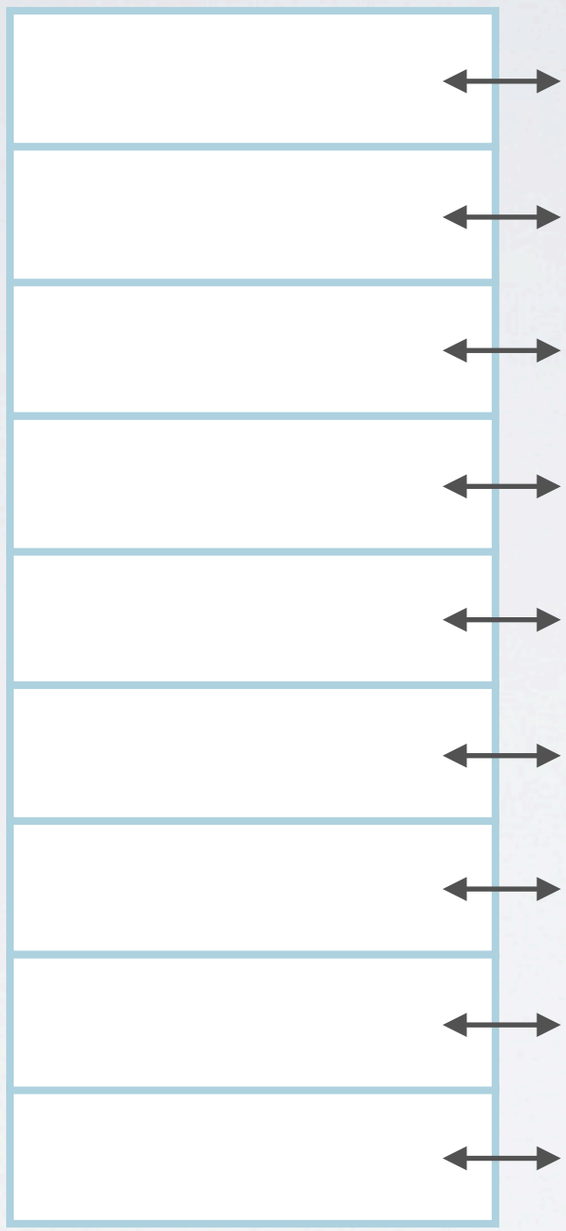

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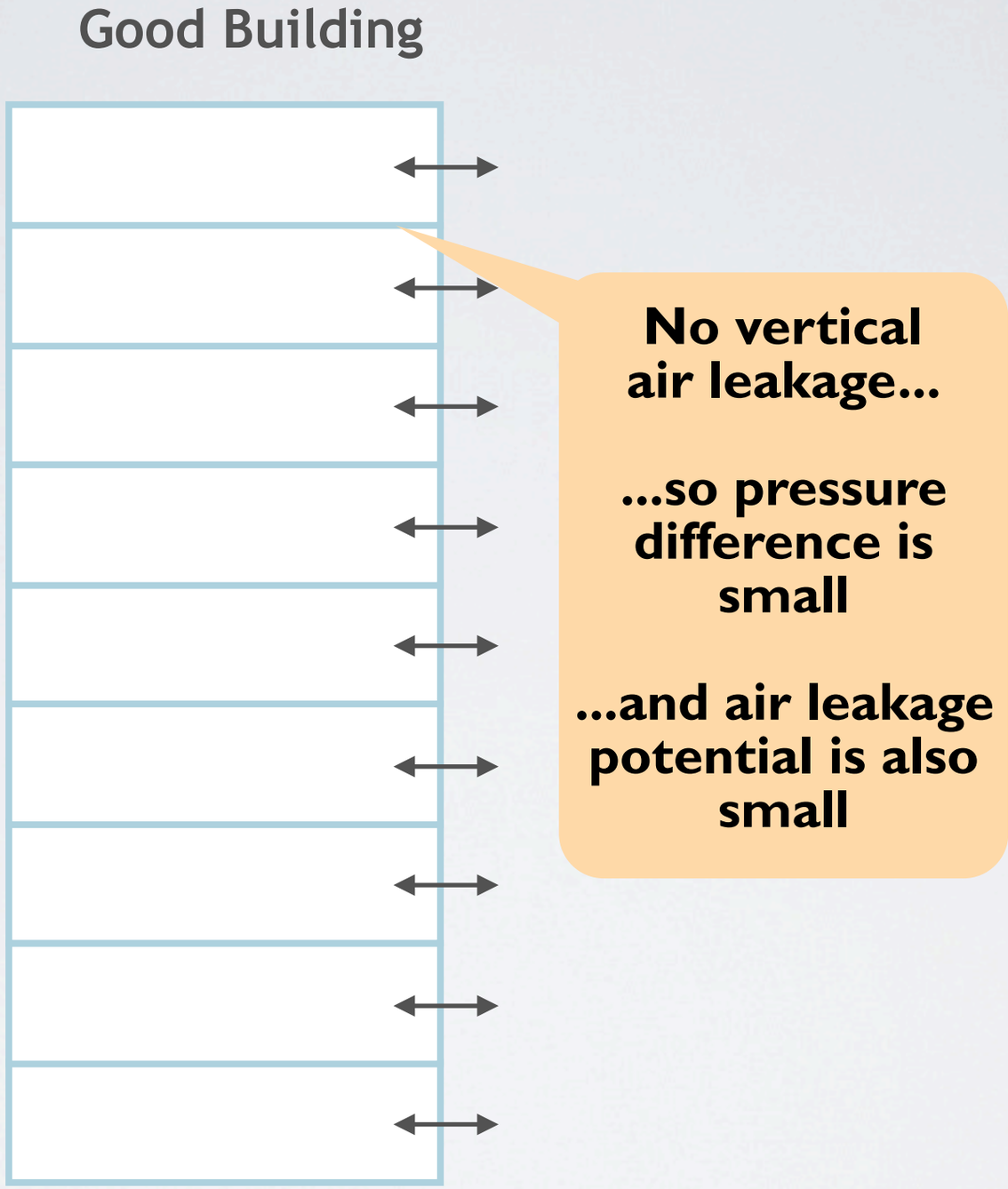
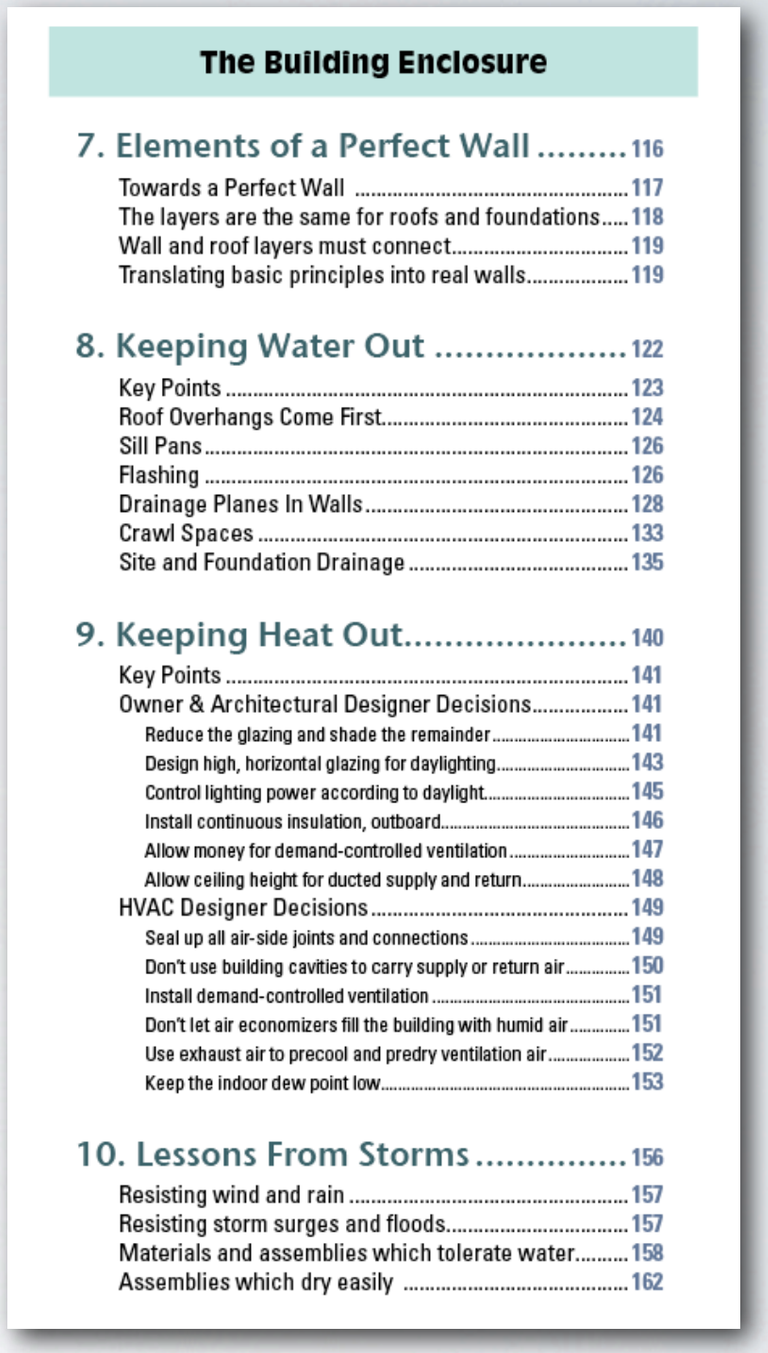


# Reason #3 - FIRE SAFETY



# Summary - Suggestions for architectural design



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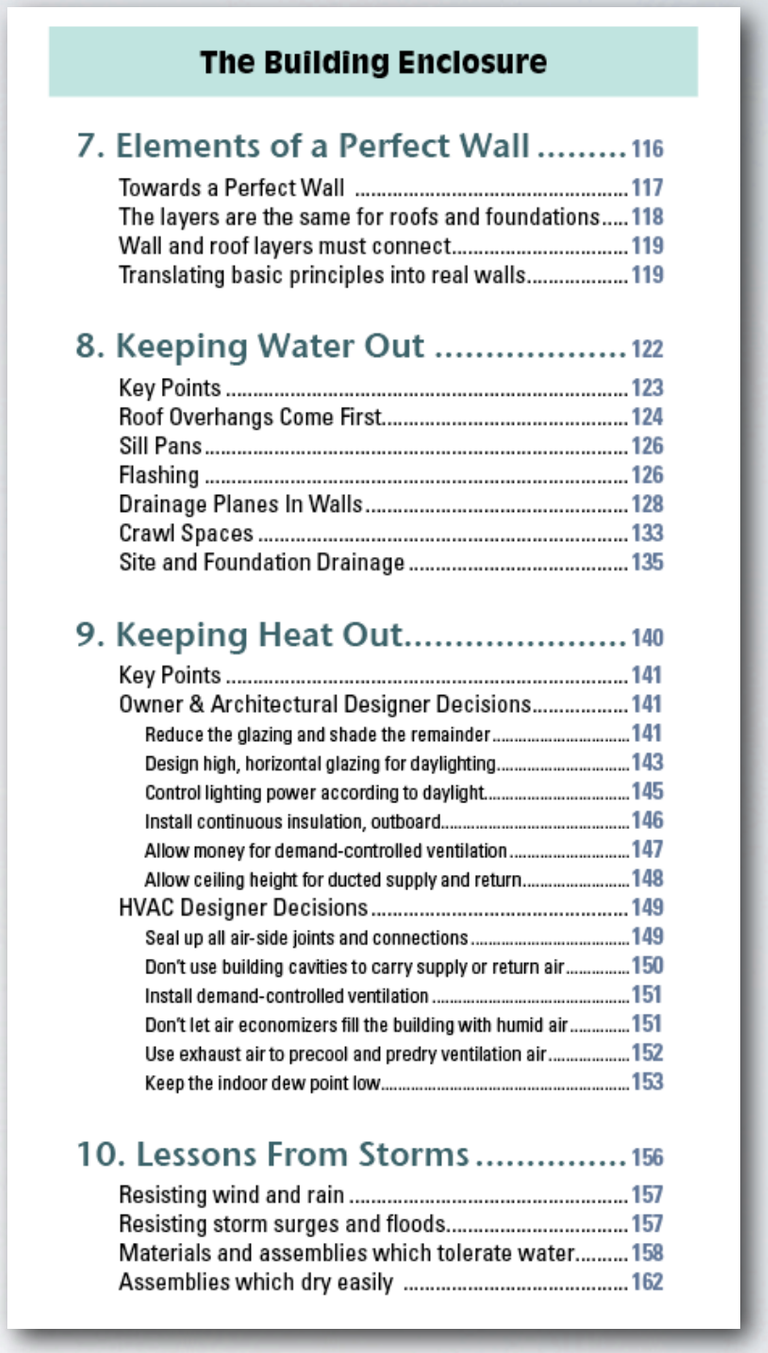
## 3 of My Favorite Suggestions:



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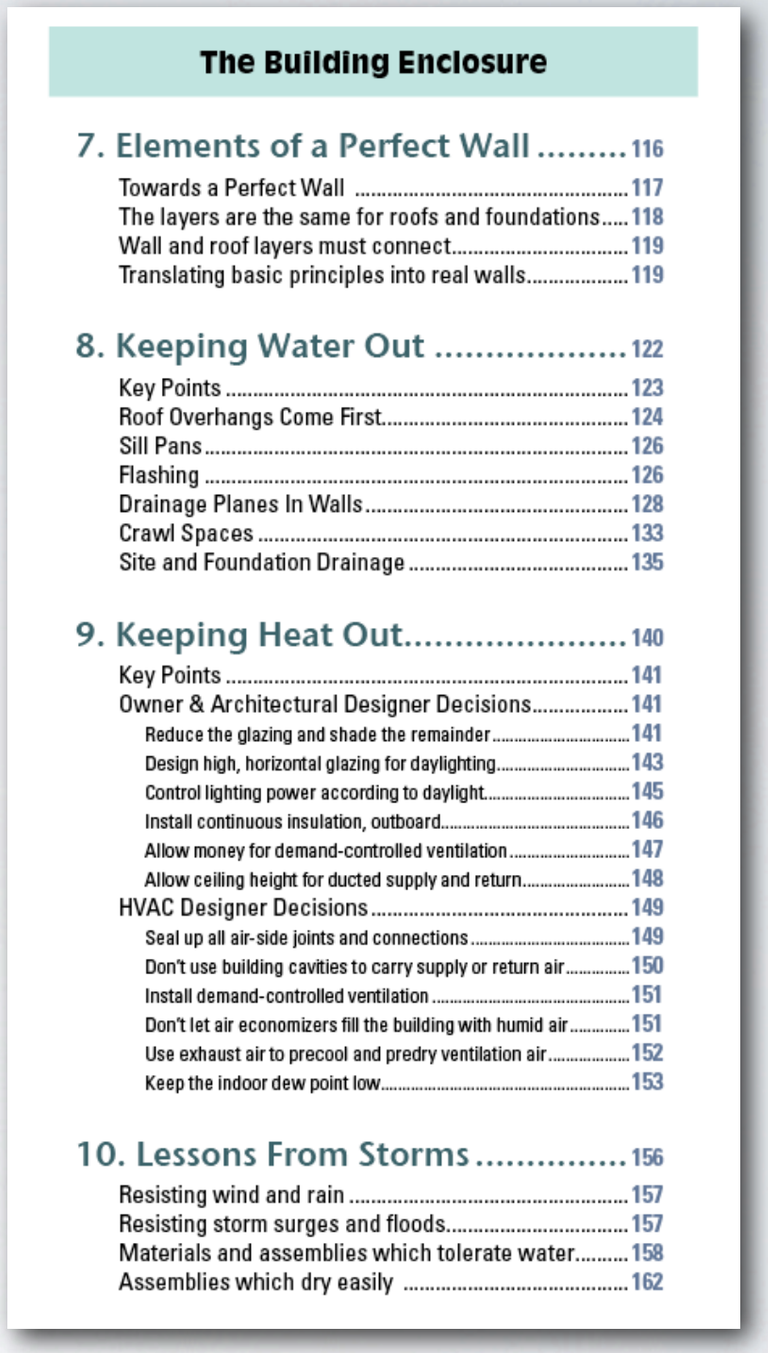
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.



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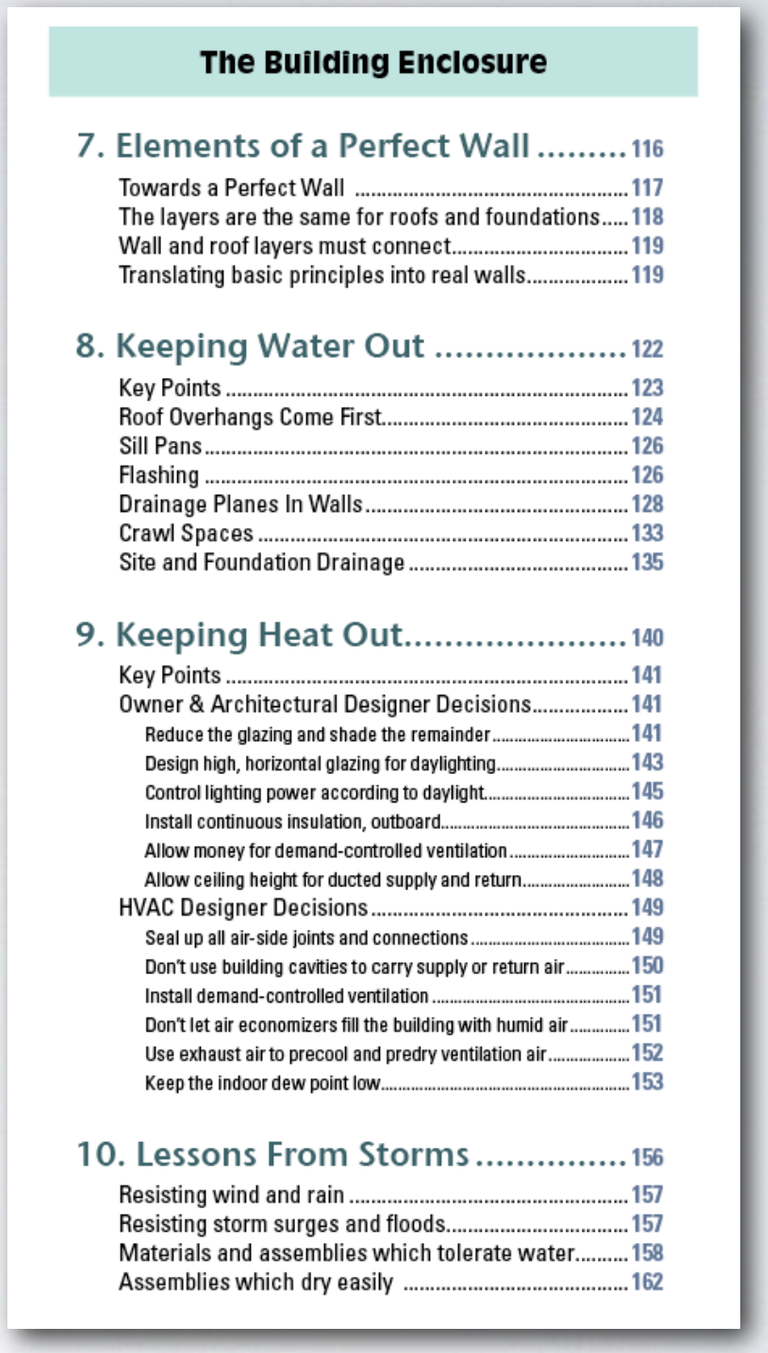
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.



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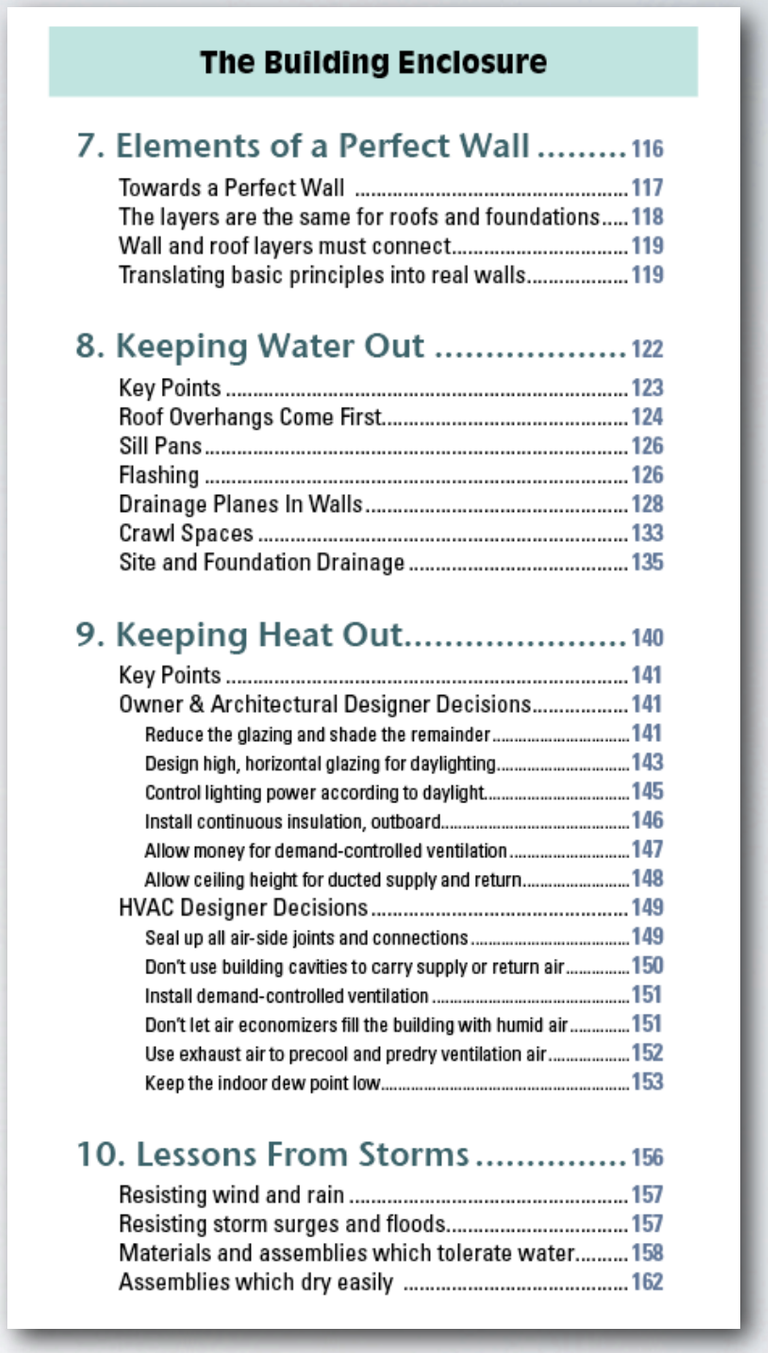
## 3 of My Favorite Suggestions:

- **Focus on glazing**... Daylighting and low solar heat gain.
- **Stop envelope air leaks**... no more gaps, cracks and holes.
- **Indoor insulation and air tightness**... For partly-cooled buildings.



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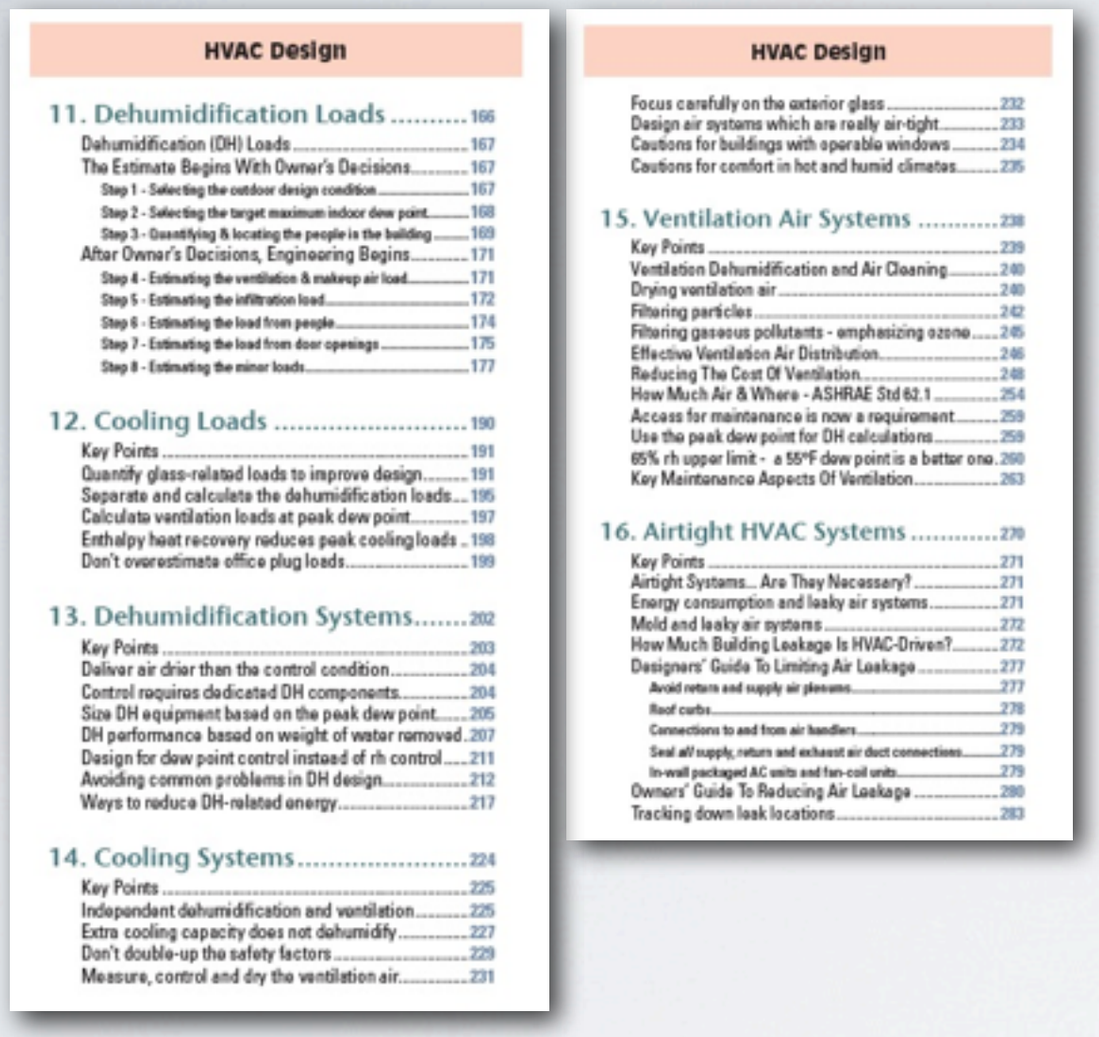

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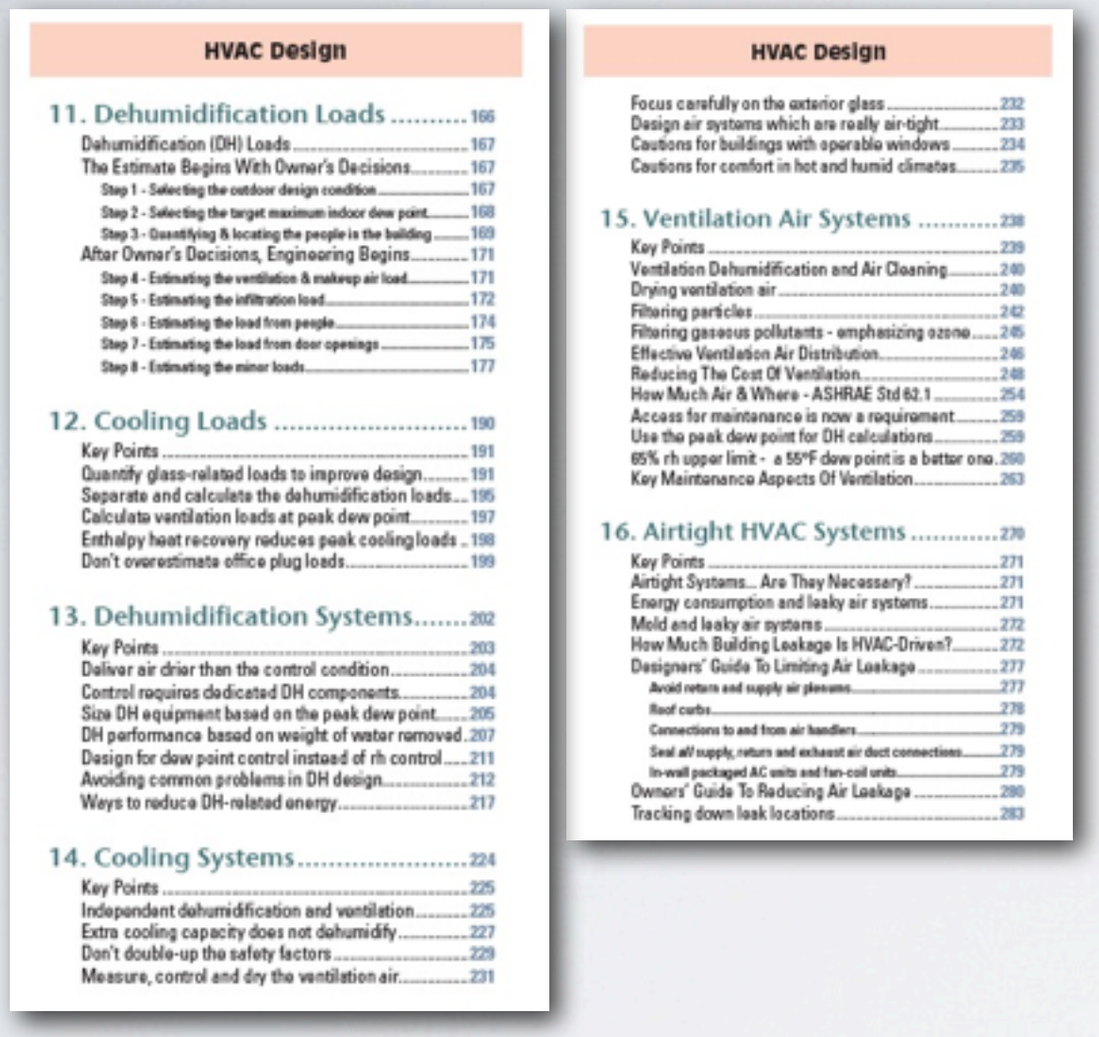

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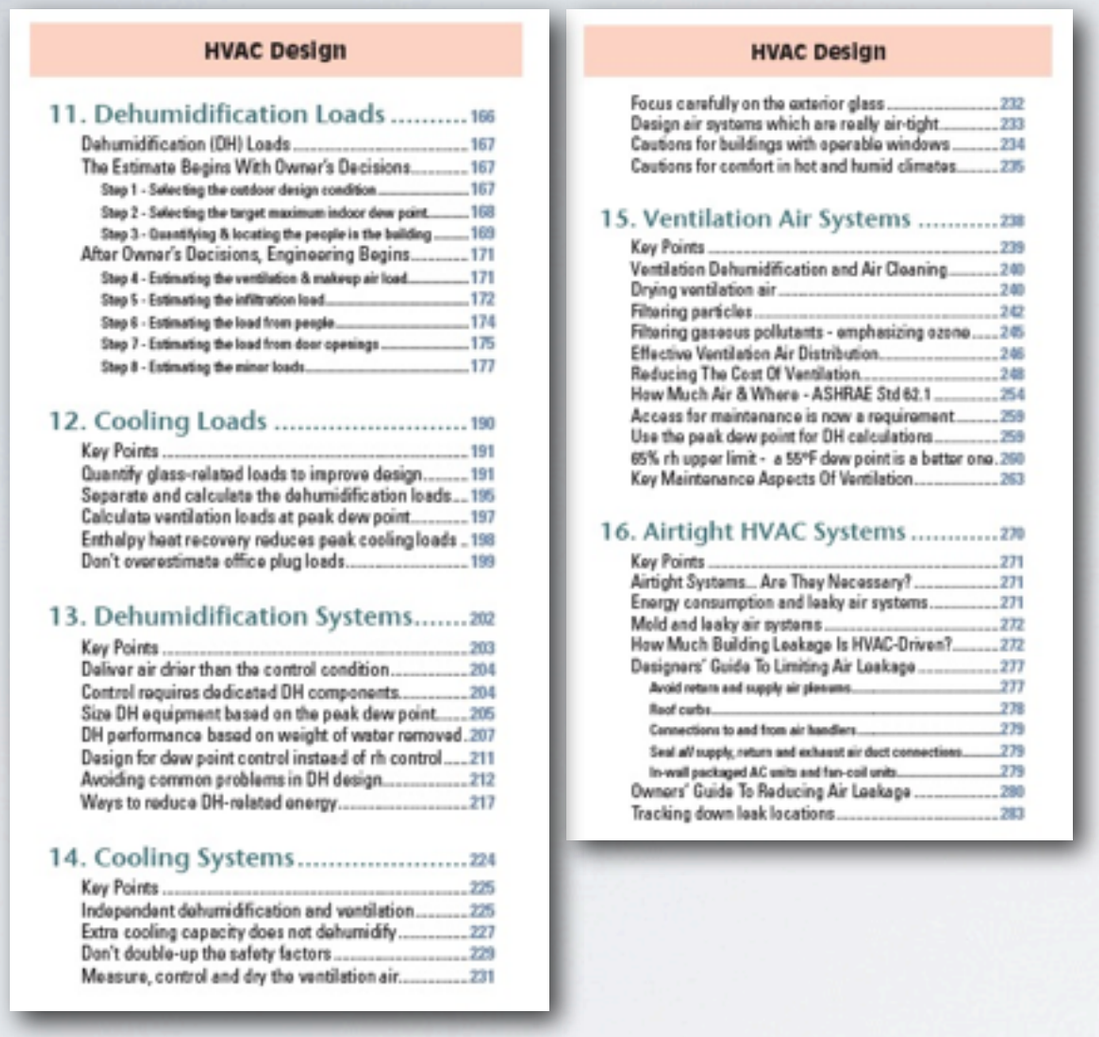

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- **Dry, measure and vary the ventilation and makeup air at all times**... no more wasted energy and no flood of humid air.

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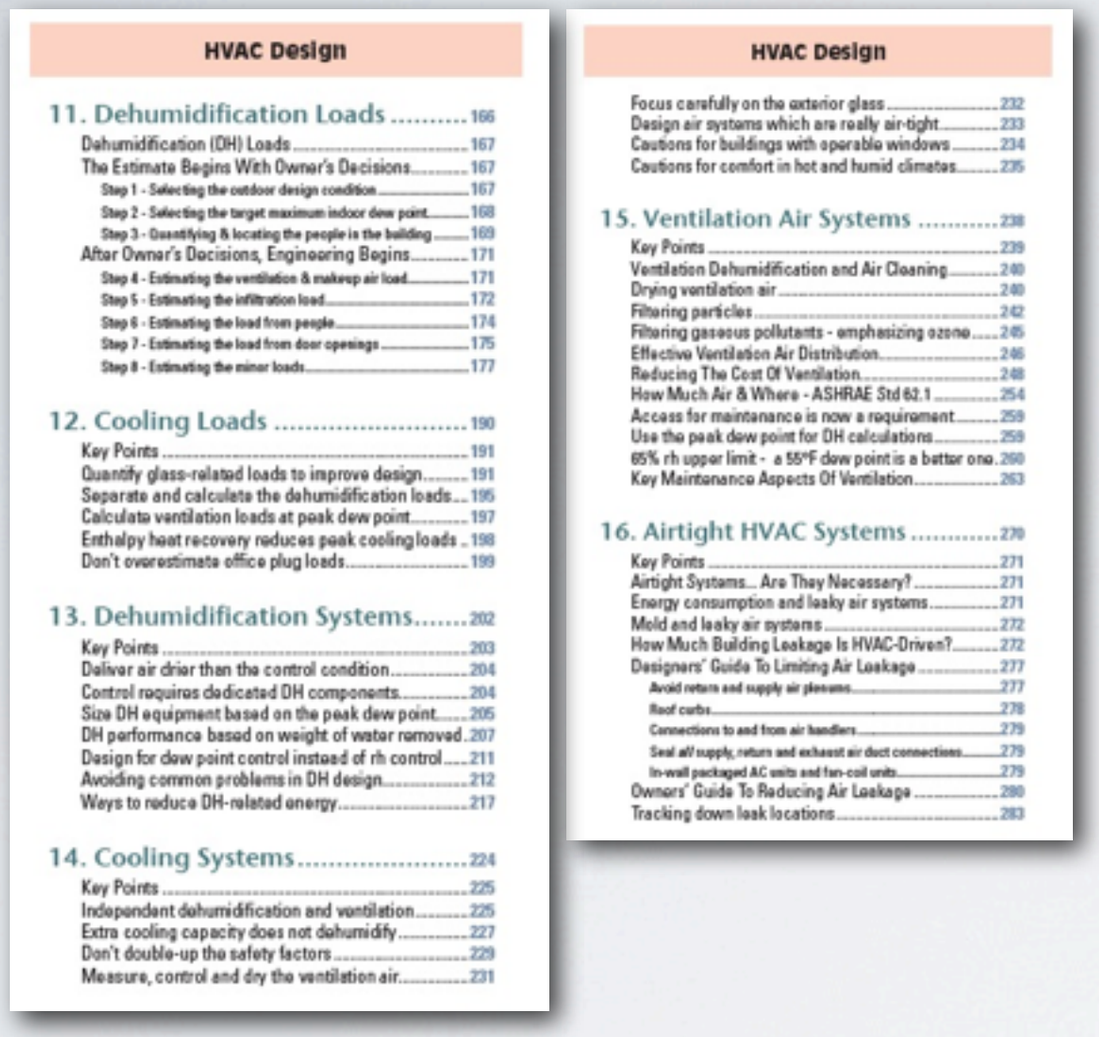

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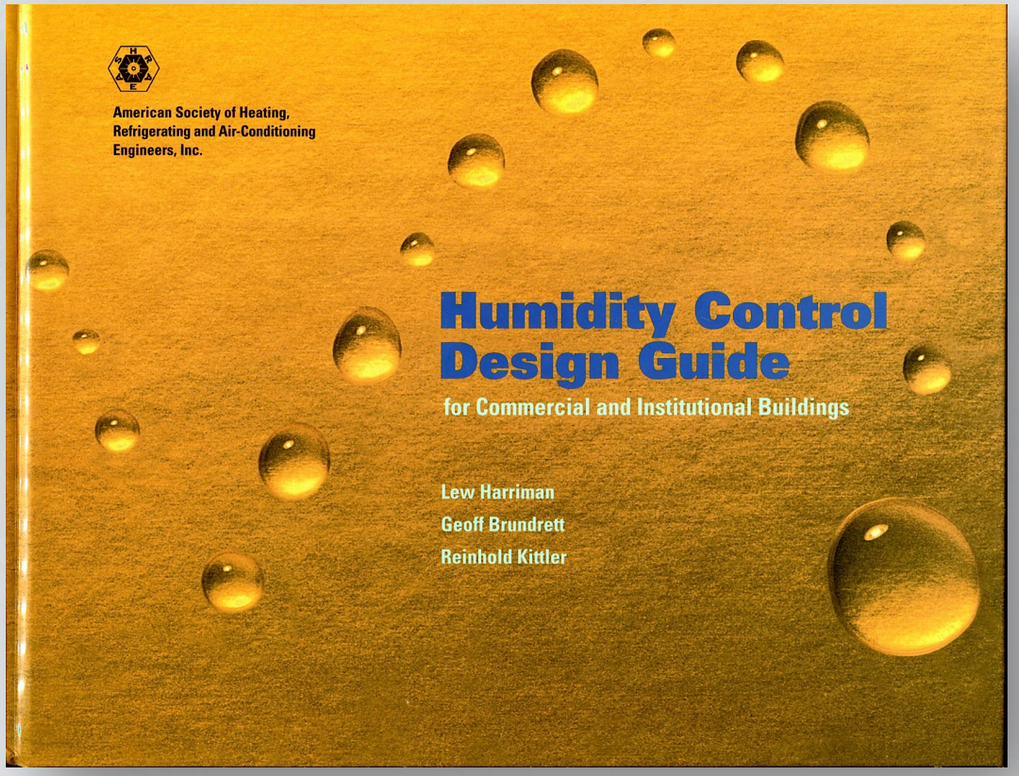
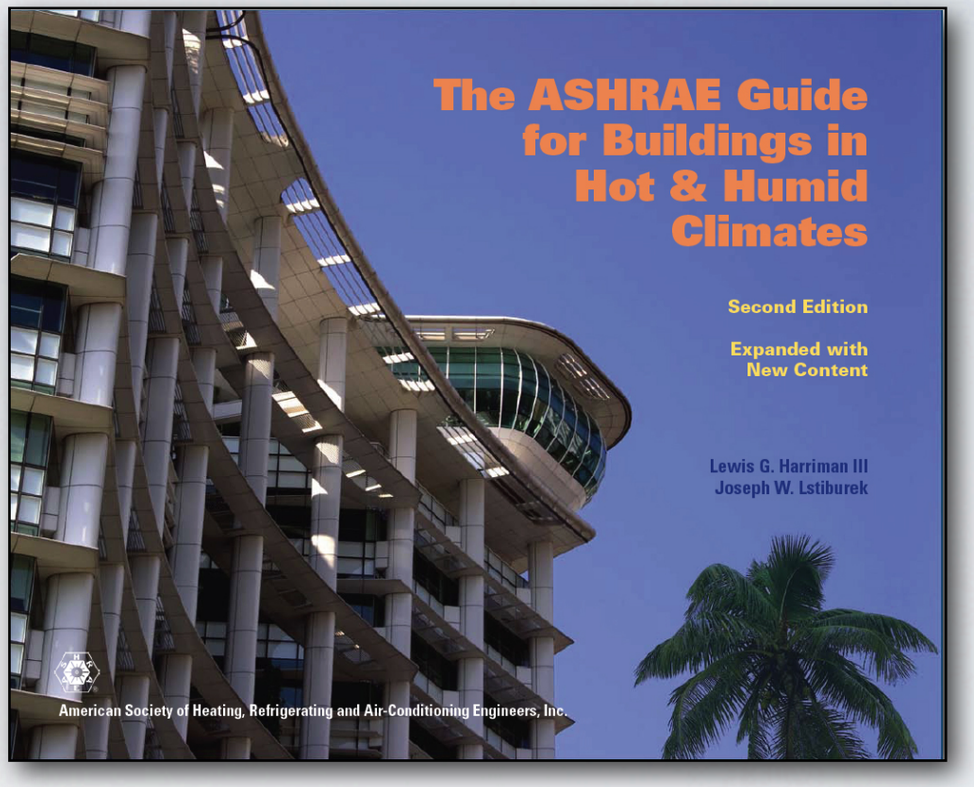
- **Dry, measure and vary the ventilation and makeup air at all times**... no more wasted energy and no flood of humid air.

- **Use ASHRAE peak dew point, calculate humidity loads and install a dehumidifier**... cooling tons do NOT automatically provide dehumidification.

# Further Resources



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2011 - 2013 Chair TC 1.2 - Moisture Management in Buildings
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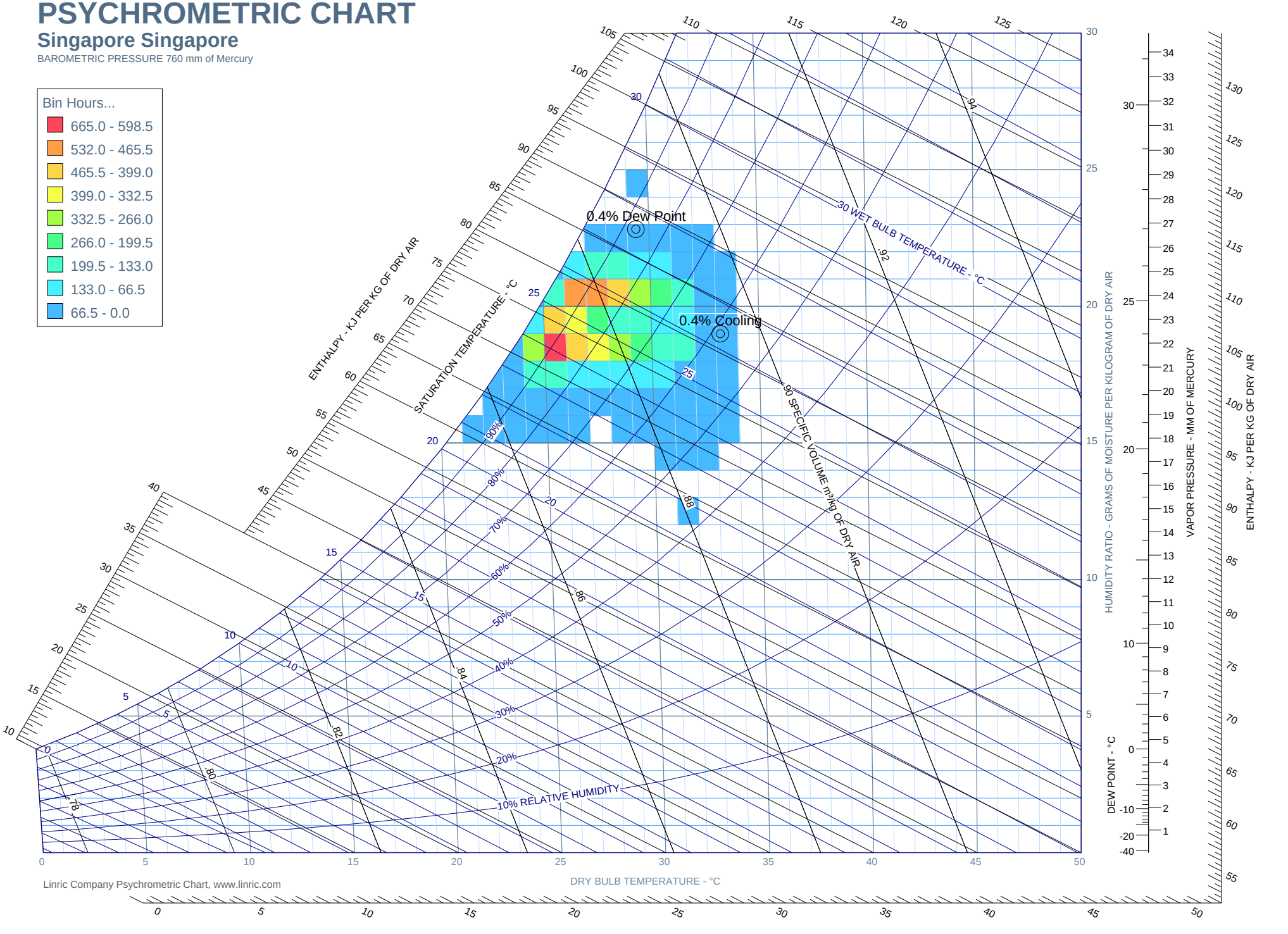
# PSYCHROMETRIC CHART

## Singapore Singapore

BAROMETRIC PRESSURE 760 mm of Mercury




Linric Company Psychrometric Chart, www.linric.com