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Memorandum

Date: January 13, 2012

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Jay Santos, Larry Luskay, Darren Goody, Murphy O'Dea; Facility Dynamics Engineering (all via e-mail)

From: David Sellers; Facility Dynamics Engineering

Re: Variable Flow Refrigeration (VRF) Systems; the Field Perspective

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The purpose of this memo is to highlight some of the commissioning and operational issues we have encountered in our experiences with VRF systems on the UC Berkeley Campus. To some extent, it is the narrative for the PowerPoint I forwarded previously, so the two complement each other. Thus, I have included a copy of the PowerPoint slides as an Appendix and will reference them for illustrations rather than reproduce the illustrations.

If you are reading this memo in the electronic version, the table of contents below can be used to move around quickly in the content. Click on the topic of interest in the contents list below and you will be linked to that location in the document. Use the back arrows on the tool bar to get back to where you came from[1].

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[1] Exactly which back-arrows and which tool bar will depend on whether you are reading the document in Word or Acrobat and which version you are using. But so far, the feature seems to work with all of the versions the author has been exposed to.

Introduction

Related Slides – 1 through 5

Slides 2 and 3 present FDEs corporate and my personal biography in the context of VRF systems. In the United States, the VRF approach is a relatively new player in the HVAC industry and as commissioning providers, we have just started to see these system reach the field. Thus, it is important to recognize that the information and recommendations that follow are from the field vs. the design perspective, and that they are based on limited exposure during construction, start-up, commissioning, and retrocommissioning of VRF systems in a number of facilities over the course of the past year to two years. In other words, they are based on experience with tens of units and systems vs. hundreds.

Having said that, at their core VRF systems amount to field erected refrigeration systems consisting of:

- Fan coil units, typically including variable speed fans, that serve the loads with a direct expansion coil that can be used to heat or cool;
- One or more condensing units[2] that reject unneeded heat to atmosphere, which at a fundamental level, are very similar to conventional condensing units;
- Interconnecting piping, which must be designed and installed just like refrigeration piping serving any other refrigeration system; and
- A control network and refrigerant distribution controllers, which orchestrate the operation of the system.

It is in the distribution controllers and control system algorithms where much of the “magic” of the VRF technology lies.

My point in bringing this up is to say that thus far, the issues we encountered were not really with the VRF technology; i.e. the “magic” in the control algorithms and distribution controllers. Rather, they were with the application and implementation of the technology. That is to say that most of the issues are similar to the issues we see on virtually all of our commissioning projects. This is the point of the two bulleted lists on slide 5.

Overview of the Technology

To expand a bit on the bulleted list in the preceding section, VRF systems use distribution controllers and control algorithms to allow multiple evaporators in a direct expansion system to be served by a central condensing unit(s)[1]. In and of itself, serving multiple evaporators with one or more compressors and condensers is not a new idea. You can find examples of it in things like the Trane Refrigeration Manual with publication dates in the late ‘60’s and early 70’s (if not earlier; those dates are the ones in my copies).

What makes the VRF technology unique is that active techniques (the distribution controllers) vs. passive techniques (the physical piping configuration) are used to control how refrigerant flows around in the system. This active approach to refrigerant distribution allows heat that is rejected in one zone to be used in another zone where heat is required and also allows significant turn-downs in capacity to be achieved.

[2] Multiple units can be ganged together or “twinned” to increase capacity.

As a result, the systems can approach the flexibility and performance of a chilled water system but without the added complications and energy burdens of distribution pumps. However, the VRF technology itself is not without complications and limitations.

- The distribution controllers are technically complex devices, containing multiple solenoid valves, check valves, electronic expansion valves, heat exchangers and solenoid valves, all controlled by proprietary software algorithms. Perhaps the best way to gain some insight into this is to take a look at slide 10 and the link it contains.
- This technology tends to be located in congested ceiling spaces. The implications of this are discussed further under *Access and Serviceability*.
- The turndown capability is not infinite, although infinite turndown seems to be the perception unless you have had some experience with the systems; certainly it was mine until I started working with the equipment. In general terms, at the zone level, you can anticipate turning down to 20-25% of rated capacity and at the system level, 20% or so. The implications of this are further discussed under *Design Integration*.
- The distribution piping contains refrigerant (vs. water in a chilled water system). Thus the implications of a leak are significantly different. This is further discussed under *Refrigerant Considerations.*
- Because the distribution piping contains refrigerant, the installation practices are different and more stringent than what would be required for installing chilled water piping. This is further discussed under *Installation Considerations*.
- Like chilled water fan coil units, the VRF fan coils are more attuned to addressing space heat gains and losses rather than the challenges associated with handling ventilation air. This can present a number of design challenges, which are further discussed under *Design Integration*.
- Strict interpretation of industry leading energy codes like California's Title 24 and ASHRAE guidelines will mandate that the VRF fan coils units include an economizer process. Since the VRF manufacturers are in the VRF business, none of them manufacture an economizer. Rather, they rely on after market, third party solutions, which can present integration challenges. While this will likely not be a major concern in hot and humid environments like Hawaii, I will touch on the issue under *Design Integration* to ensure that the issues are recognized if the topic comes up.
- The technical complexity of what is being managed by the (proprietary) VRF control systems must mean that they "know" a lot about what is going on with the zone, equipment and system. However, experience to date indicates that not much of this information is available for "sharing" across an interface like BACNet or LonTalk. As a result, from the perspective of an Operator Work Station (OWS) serving the central control system of a facility with VRF systems in addition to other, more conventional systems, there is a lot that you cannot see or control. While there is probably merit in minimizing access to critical control functions inside the VRF equipment, being able to at least <u>see</u> what is going happening, including the diagnostics that are running in the VRF control platform would seem to be desirable. And, even for basic functions like scheduling and set point adjustments, there can be challenges on a number of fronts, which will be discussed under *Control System Integration*.

The bottom line (and this is an opinion vs. an industry consensus) is VRF systems likely represent an attractive *design alternative* in certain situations. But they are not a panacea and certainly are not without their issues and limitations. Thus, like any other HVAC strategy, they require careful attention to the details of the application and design, in terms of the dynamics of the loads served, the capabilities of the craftsmen and operators charged with implementing and maintaining them, and the constraints of budget.

Access and Serviceability

Related Slides – 6 through 26

By their nature, the final control elements in an HVAC system, be they a Variable Air Volume (VAV) terminal with reheat coil, a fan powered VAV terminal, a chilled water fan coil unit, or a VRF fan coil unit, all will tend to be installed at or near the zone they serve. Frequently, the installed location is in the ceiling space of the zone or an adjacent space.

This can introduce a number of challenges with regard to the long term servicing of the unit including:

- Access challenges created by the use of the space. Slide 6 and 7 are of the same space before and after finishes. What you can’t see in slide 7 is a very high quality conference table that fills the entire room and cannot be removed from the space without disassembly. This means that to service the VRF terminal shown in slide 6, you will be working off a ladder that cannot be conveniently located over a table that is probably worth more than your house in the Law School Dean’s conference room (think about that for a minute). In addition, the very nice looking ceiling requires a special service tool to remove the ceiling tiles, which is delicate in nature and tends to break after about the 3rd or 4th tile you remove.
- Out of sight, out of mind challenges; i.e. if you can’t see it or hear it, you forget that it’s there and that you need to maintain it until it fails. The most likely thing to require relatively frequent service in a fan coil unit (VRF or otherwise) and/or a fan powered terminal unit is the filter. You probably are going to need to replace it every 6 to 12 months, even if you have to do nothing else to the fan motor and its related variable speed controller, the cooling coil drain pan, and the controls.
- Related to the preceding, detecting a failure can be a challenge since it is often based on the zone occupant’s perception of comfort. HVAC processes can be insidious in that they can fail in a very energy intensive manner and still deliver a comfortable (or at least tolerable[3]) environment.

For VRF systems, these issues are compounded by the fact that the VRF fan coil unit is probably at the high end of the spectrum in terms of complexity when compared to other technologies, with a simple (not really, but sort of) VAV terminal representing the low end. A VRF fan coil (or any fan coil and also a fan powered box) is basically a little tiny air handling unit sitting above the ceiling with all of the maintenance requirements associated with an air handling unit but with limited access as compared to a mechanical room or even a rooftop location.

[3] In some facilities, there is a somewhat low expectation of HVAC performance. Tenants may tolerate comfort conditions that fall well short of design goals for a number of reasons including nobody paying attention when they complain, things being better than the last place they were, and things getting worse instead of better if someone responds to their complaint

Complicating all of this for VRF systems is the fact that the fluid pumped around is a refrigerant, not water which has a number of implications in terms of the hardware that will exist at the fan coil units (expansion valves vs. a control valve), leakage, and piping techniques, all of which will be touched on further later in the memo.

This issue can be compounded by the fact that the manufacturer's access recommendations (or the interpretation by the design team) may not reflect the reality of servicing the equipment in an actual installation. In other words, you could comply with the letter of the manufacturer's recommendations and still find yourself in a world of hurt in a real service situation if you for instance:

- Had to access the side of the distribution controller that was opposite the access hatch with only 3 to 4 inches of space available above the unit, 8 to 10 inches of space available on either side of the unit and 8 to 10 inches of space available below the unit.
- Had to service a unit that was 10 feet above a hard ceiling that was 12 feet above the floor via an 18 inch by 18 inch access panel.
- Had to braze in a new expansion valve into the guts of a distribution controller above a ceiling with limited access;
- Had to remove a branch controller that was bigger than the ceiling access panel size specified by the manufacturer.

Slides 13 – 26 endeavor to contrast what the installation manuals from one manufacturer show vs. the reality of installed equipment and some of the service procedures that might be required. Note that a lot of the pictures used to illustrate the manual are taken from a perspective that would be virtually impossible to obtain in the field if the units were installed per the manual.

This takes you to the installation manual recommendation illustrated in slide 24 about *dismounting the unit from the ceiling* which involves breaking 22 line sets, a condensate drain, power and control wiring, and then pulling the unit out through a hole that is smaller than it is.

Installation Considerations

Related Slides – 27 through 41

The practices required to install the refrigeration piping for VRF systems are no different from the practices used for any other refrigeration system. But, a fitter who is a great chilled water piping installer may not be a great refrigeration piping installer without proper training, equipment, and support.

Our experience so far has been that even "factory trained" technicians take short cuts that violate both good practice in terms of refrigeration piping (cleaned and capped piping, nitrogen purge, etc.) as well as the instructions in the installation manual (which are basically the same as the recommendations you would find just about any place for installing refrigeration piping). Slides 27-30 illustrate what we are seeing happen out in the field.

All of the preceding aside, R410, which is a common refrigerant in these systems, is relatively new to the field. I will touch on the refrigerant specific issues in the next section, but in terms of installation, there are details associated with installing an R410 system that are subtle but significantly different from way R22 systems, for instance, are installed which may not be recognized by field technicians who have not worked with the refrigerant before.

- The technical specifications for the flares required by R410 systems are slightly different from R22 flares. The differences are *fractions* of a millimeter if you think of them in terms of the diameter of the finished flare. But if you do the math, they amount to significant differences in the seating area provided by the flare; 8-17% more surface area. There is probably a reason for that related to the significantly higher pressures that an R410 system operates at when compared to R22 (see slide 32). I got a bit obsessed with this at one point and researched it and then wrote a fairly long memo on the details, which I have included in *Appendix 2 – Flare Joints* if you want to know more.
- Because of the higher pressures, a flaring tool that rolls the flare vs. pressing the flare will produce a better joint. But making the recommended rolled flare requires a different type of flare tool from the one that most techs probably carry in their tool set.
- Good practice and the manufacture's recommendations indicate that the flares should be lubricated with refrigerant oil before tightening them. The problem is that if you did not use R410 oil, you would contaminate the refrigerant system, causing early failures. R22 oil is totally incompatible with R410 (and vice versa I think). In fact, all sources I looked at recommended that you have a totally separate set of tools for R410 to guarantee that you did not contaminate the system with oil from a different type of refrigeration system.
- The manufacturer's literature recommends a very specific torque for the flare nuts and the use of two wrenches for making up flare joints. If you look at some of the pictures in slides 36, 38, and 39, and recognize that the flare nuts are right next to the distribution controller box, you will probably begin to appreciate how difficult this might be to actually accomplish. At least one installer who we know and respect concluded that they were better off making up the flare joints to the branch controller on the bench before they hung the controller. The bench mounted pipe was configured to place the field joints further out in the piping system where they had more room to work. Even though the practice added a brazed joint to the system, they came out ahead because they experienced fewer leaks at the flares when they tested the piping system and prepared it for charging.

One of the things that concerns us about the preceding list is that the issues that are created by improper installation (sludge and acid in the refrigerant oil, minor leaks, corrosion, motor problems) may not (probably won't) show up until after the warranty runs out. This means the Owner will be faced with dealing with issues that really are consequences of poor installation practice but will have no recourse to seek compensation from the installer who was responsible for the problem. As a result, we believe that construction observation and rigorous testing and documentation of how the piping is installed will be critical for these systems.

One piping issue that we did not witness directly but are aware of is related to the expansion of long runs of copper piping as they go through the temperature changes associated with operating these systems. By their nature, these systems can have long runs of copper pipe. Given copper's high coefficient of thermal expansion and the temperature swing the system can see, long runs that are not properly anchored, guided and installed in a manner to accommodate expansion can flex to the point of failure, tear anchors out of walls or shift walls that are more securely anchored to the pipe than the surrounding structure.

Again this is nothing that is directly the result of using VRF systems; it is just an issue that is not recognized at this point by the teams installing the systems and thus leads to problems that are then blamed on the VRF technology. But the reality is that any copper pipe (like one carrying hot water for instance) that goes through a temperature change requires consideration with regard to how it is installed, guided, and restrained to deal with the anticipated expansion.

Refrigerant Considerations

Related Slides – 41 through 45

There are a number of things that come up with R-410 systems that may not come up with more conventional refrigerants. One is that R410 is actually a blended refrigerant (a mix of one or more refrigerants; in this case a 50/50 blend of HFC-32 and HFC-125). Technically, as I understand it, R410 is classified as a "near azeotrope" (see slides 43-45).

In practical terms, what that means (again, as I understand it) is that if you have a leak, you could lose more of one of the refrigerants in the blend than the other, which shifts the performance of the blend. In turn, that means if a leak is large enough, you will need to remove the charge and then recharge the system to restore design performance. This contingency can come up for a number of reasons.

- One is that you simply have a major leak resulting in a significant loss in the refrigerant charge.
- The other is that you have a new contractor connecting to an existing branch controller installed by a different contractor to expand an existing system. The new contractor may (with some justification) claim that they are reluctant to connect to the existing piping network without removing the charge, re-testing the piping existing piping system for integrity, re-evacuating it and then re-charging the system. This can represent a significant and unanticipated expense.

Leaks in refrigerant systems can be less obvious than leaks in say, a chilled water system. Compare dumping a gallon of water on your desk (which is what might happen if a chilled water system were to develop a leak) with the oil film that might appear on the pipe and fittings adjacent to a leak in a refrigerant line located in the ceiling space above your desk. In both cases, you lost your working fluid. But in the former case, it is probably a lot more obvious than it is in the latter case to the casual observer, a.k.a the tenant, by whose complaints we frequently judge the success or failure of our HVAC designs.

From a code standpoint, in at least one jurisdiction, we have had the authority insist that ventilation be maintained 24/7 for any zone where-in a R410 line is contained. This means that even though numerous non-VRF zones in the facility are unoccupied, we cannot shut down the air handling system providing the make-up air because the non VRF zones have VRF piping passing through them.

As far as I know, R410 is not considered, technically, to be more dangerous than, say R22. But it is being treated differently from an installation where R22 lines run through the occupied space by this particular authority. I have not actually dug back into the ASHRAE/ANSI standard that governs this to see what ***I*** think it means, but in this particular instance, what ***I*** think it means is irrelevant because it is what the authority having jurisdiction thinks it means that matters in terms of getting an occupancy permit.

Control System Integration

Related Slides – 46 through 67

In our experience to date, the control system integration issues show up on two fronts. The most challenging is the integration of the VRF equipment with an economizer process, which is required by the letter of the law in California, and maybe other states. As mentioned previously, the VRF manufacturers defer the responsibility of this to aftermarket vendors, and the aftermarket vendors to not seem to understand the details and nuances of the VRF control systems. They really just put together a package of parts with a generic wiring diagram that is a statement of intent that likely will not match the specifics of the parts supplied and the VRF equipment. A lot of getting it right is left to the discretion of the installer, who is probably being pressed to complete things in a hurry. So things end up a bit dysfunctional.

Since economizers are probably not a big issue in Hawaii (i.e. you don't use them because of the hot and humid conditions), I will not dwell on that. But if you are interested, I have included an e-mail discussion I had with a VRF vendor who was about to enter the market who had seen a copy of the VRF slides I did and asked me about the details.

Most commissioning process, including ongoing commissioning rely heavily on trending. For VRF systems, the trending required is complicated by the fact that many of the points you would want to use are not visible via the BACNet interface to the VRF control system or are not available as outputs from the packaged control system on the economizer, or both.

This makes the concept of using a small controller from the site wide control system product line to provide the economizer functionality and integration with the VRF fan coil desirable. And, including such a controller even if there is no economizer to simply monitor key parameters and control the ventilation air damper (a function which may not be supported by the VRF manufacturer) so that some diagnostics can be performed without having to access the unit in a potentially difficult location could be desirable and cost effective. Potential monitoring points might include filter status, mixed air, return and discharge temperatures and maybe even surface temperatures on refrigeration lines, which are an indicator of the pressures. Depending on the points selected, it may be possible to use one controller to integrate multiple VRF fan coils.

The other area where control system integration issues showed up for us is related to how the available points in the VRF system are mapped across a BACNet interface for use by the site-wide control system. There would seem to be two elements to this.

1. The proprietary control systems that orchestrate the VRF systems have a lot of information available. But not much of this information is available for transfer across the BACNet interface. So, while you can probably implement a schedule across the interface, you cannot see much about how the VRF units are operating (refrigerant pressures, diagnostics, etc.) across the interface. Nor can you see the fairly sophisticated diagnostics that are running on the VRF control platform.

2. As is the case for any BACNet (or other) interface, the specifications need to clearly define that all of the available points be mapped across the interface. Otherwise, basic, very useful things, like the ability to schedule a unit, may not be available from the central control system (without paying for a change order).

Design Integration

Related Slides – 68 through 75

There are a number of design integration issues that have become apparent to us over the course of our limited exposure to VRF systems.

1. One is that designers appear to view the VRF technology as more of a packaged solution than a designed solution and directly or indirectly delegate a lot of the design details to the vendor and installing contractor. While the details of how you run the refrigeration lines, locate d controllers, combine fan coil zones with distribution controllers, combine condensing units, etc. are all very vendor specific, and thus require significant input from the vendor, there are other design issues that require a very specific response from the designer.

   Examples include integration with an economizer process, which the vendors will literally say is not something they do, even though the failures of poor economizer integration will be blamed on them. Integration with the site wide control system and the ventilation system are other areas requiring more designer input than a note on a schedule and boiler plate specifications.

2. Ventilation air for VRF systems tends to be provided by a separate, independent system. The performance requirement(s) for the outdoor air system needs to be closely coordinated with the requirements of the VRF system. For instance:

   i. Make up systems tend to pressurize the Outdoor Air (OA) supply duct to the VRF systems (vs. having the system draw air from an outdoor air intake, which makes the duct negative relative to the area served). So, if one VRF system shuts down while others served by the OA supply unit remain in operation, the OA damper for the VRF unit needs to be closed, otherwise, the OA system will blow air through the unoccupied zone, which may or may not be useful. And, the OA system needs to be able to back off in response to the reduced requirement for ventilation to preserve the over-all efficiency of the system.

   ii. The OA system needs to temper that outdoor air in a manner that ensures that it is introduced to the VRF systems at conditions the VRF systems can deal with. VRF systems, for instance, may not be able to deal with heavy dehumidification loads.

3. Sometimes, the ventilation air system also becomes the source of outdoor air for all operating modes, including the economizer process. And the designated ventilation air system may serve other conventional zones, especially if an existing system was used. In the case of at least one project, the ventilation system served VRF systems and also previously existing constant volume reheat zones that were outside the scope of the VRF project.

   As a result, someone needs to decide if the needs of the VRF systems "trump" the needs of the constant volume reheat zones or vice versa. For instance, a colder supply air temperature generally will minimize the energy required by the VRF systems since the refrigeration will not need to run to provide cooling as much as it would with warmer supply temperatures. But, colder supply temperatures can work against the energy efficiency of a constant volume reheat zone.

   In at least one instance, the design team left it up to the commissioning provider to figure this out. On the bright side, this is ultimately the best approach since you end up asking the building to tell you what the right set point it. But, making an informed decision requires a lot of field testing and trending, which may not be supported by the project commissioning budget.

4. As mentioned previously, there seems to be an impression in the design community that VRF systems have an infinite turn-down capability; at a the zone level, the limit is probably 20-25% of rated capacity. If the load drops below that point, then the zone fan coil will probably start to show temperature swings vs. modulating the capacity to match the load (see slides 68-69).

   Truth be told, most chilled water systems probably have a similar limit. But, because of the thermal inertia represented by the piping system and the water it contains, for a system that is large relative to any given load, the loads can probably seamlessly modulate from full capacity to zero as long as only a relatively small percentage of them attempt to do it at the same time. In other words, the thermal mass of the system allows a small percentage of the zones to achieve near infinite capacity modulation.

   This is not the case for VRF systems. As a result, terminal units that are oversized will short cycle at low loads and deliver space conditions that swing significantly. This will tend to drive the occupants crazy for a number of reasons. If (for instance) it results in ruined research (as was the case at a Physics lab building on a major University campus) the pressure on the facility engineering department to do something different (or not have done what they did) can be significant. In less demanding occupancies, it can still result in occupant dissatisfaction that manifests itself as, say, smashed thermostats.

   Frequently, we believe this happens because the potential ultimate load is unknown. In other words, the future tenant, when asked about what the load might be in their space, indicates that they probably will initially be reading books about nuclear reactor design. But at some point in the future, they may decide to build a small working nuclear reactor based on what they read.

   As a result, the design team sizes the VRF unit for the nuclear reactor, meaning that even if the VRF unit is turned down to its minimum capacity, it will still exceed the current (reading books about nuclear reactors) load and will start short cycling.

   If the actual working nuclear reactor never materializes, then there are a number of unfortunate issues.

   - Funds were expended for machinery and the infrastructure to support it that were not necessary to serve the real load. In other words, you put in 4 tons of capacity to serve a load that was 1 ton now and forever more.
   - The oversized equipment short cycles, which means the space temperature swings significantly.
   - The oversized equipment short cycles, which means it wears itself out much more quickly compared to what would happen if it could meet the load and operate in some sort of steady state mode.

Conclusions and Recommendations

Based on our experiences to date, as outline in the preceding discussion, our conclusions and recommendations are as follows:

- Many of the field issues we are seeing with VRF systems are really no different than the field issues we see with any type of HVAC equipment. You still have to properly design and install the system.
- The VRF technology itself seems mature and reliable if properly applied and implemented. Thus it may represent a viable design *option* for some situations.
- By their nature, VRF systems will tend to place some fairly complex technology (the distribution controllers) in locations with difficult access. As a result, we think there may be merit in rethinking how you go about installing distribution controllers. For instance, as an industry, we justify server rooms, telecom closets, and electrical closets to address the service and modification requirements associated with our electrical systems. Maybe it makes sense to consider providing “distribution controller rooms” that would allow these devices to be installed in a manner that made them more readily serviceable in the event of a malfunction or the need to add a zone. I suspect there are some piping issues that would come up if you did this, but I also suspect you can engineer your way out of them.
- Pay close attention to the piping installation techniques and testing during construction. Include thorough documentation of the process as it may be a valuable tool for demonstrating the integrity of the existing piping network to a new contractor charged with expanding the system who is reluctant to risk having his work (and reputation) contaminated by the substandard work of a previous contractor.
- Maintain complete records of all refrigerant charging operations for reasons similar to those listed in the preceding bullet.
- If economizers are desired or required, think carefully about their integration and implementation. It may make more sense to use a small controller from the site wide control system product line to implement the process and integrate it with the VRF unit rather than using the package controller offered by most of the third party manufacturers.
- It may also be desirable to include the controller mentioned above in non-economizer situations to support functions not supported by the VRF control system like controlling the ventilation damper and trend analysis.
- It may also be desirable to not close-couple the economizer (if used) to the VRF unit, providing some duct, perhaps with an elbow or two between the two to promote mixing and ensure that the mixed air temperature that is used really represents the true mixed air temperature. If you get this crucial economizer controller input wrong, then you might as well not have done the economizer because it could be working against energy savings instead of providing it.
- Bear in mind that one of the potential benefits of many VRF technologies is that they can use rejected heat from one zone (for instance, a core zone or a perimeter zone experiencing a heavy solar load on a cool day) to provide heat for a zone in the same distribution network that is experiencing a net heat loss. If you put an economizer on the VRF system, then the energy will not be recovered and while you might save on cooling, your heating costs could end up being higher than they need to be.
- Pay careful attention to the integration of the ventilation strategy with the VRF technology, especially if you are using economizers and especially if the system providing ventilation and economizer air to the VRF systems also serves other zones using other technologies like reheat.

- Pay careful attention to the installation of the VRF piping and equipment. They are field erected refrigeration systems most of which use a blended and relatively new to the field refrigerant. They require specialized tools and skills relative to what might be required to install chilled water or even more conventional refrigeration systems.
- Pay careful attention to the specification and implementation of the control system and its integration with the site wide automation and control system, including the definitions of what objects should be mapped across the BACNet (or other) interface.
- Carefully consider the real load and load profile (both seasonal and daily) that the equipment will see. It can be very undesirable to let a large *anticipated* load that *may* (or may not) exist at some point in the future determine the capacity of the equipment you install. Know what you don't know, meaning:
  - You don't know what the future load might be, so don't size the new equipment to serve it, size it for what you do know, which is the current load.
  - You don't know what the future load might be, but you know that it could potentially be significantly larger than the current load. So, make sure that your current design accommodates that contingency in its infrastructure; maybe you install extra line sets installed to the zone along with retaining space for a larger (or additional) zone fan coil unit but only install capacity for the current load.
- Design the system rather than delegating the system. While the details of the VRF technology can be very vendor specific and require a lot of vendor input to ensure that the piping is sized and installed properly, there are other important design issues that need to be proactively addressed by the engineer of record.

Hopefully this provides a "lessons learned" perspective on the application of VRF systems. I think they have their place, but you still have to think about how you go about applying them, just as you do with any technology.

David

Senior Engineer – Facility Dynamics Engineering

DAS/tbm

Appendix 1 – PowerPoint Slides from *VRF Systems – The Good, the Bad, and the Ugly; The Commissioning Provider's Perspective*

VRF Systems: The Good, The Bad and The Ugly

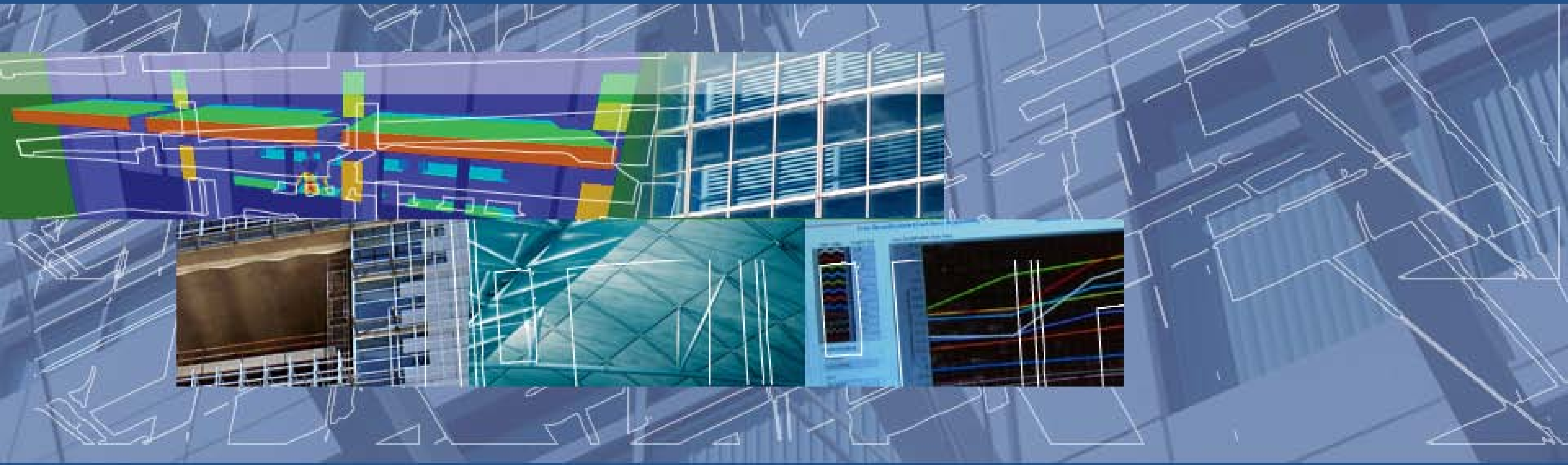
The Commissioning Perspective

David Sellers, PE, Senior Engineer

Facility Dynamics Engineering

NW Satellite Office

www.FacilityDynamics.com



The Commissioning Provider's Perspective

Early Commissioning Providers

Corporate Perspective

- Limited VRF Exposure
- Some Daikin and some Mitsubishi
- No tests developed in our commissioning database
- One system designed by a senior engineer in a past life (about 15 years ago in the Air Force)
- Several people "can hardly wait" to get inside a branch controller/point of change-over
- On person about to take factory training

The Commissioning Provider's Perspective

Early Commissioning Providers

Personal Perspective

- One new construction and one retrocommissioning project with Mitsubishi VRF equipment (both current projects)
- Exposure to built up direct expansion systems since 1976
  - Dual mode system serving an ice rink in winter and building loads in the summer (See *Mentoring Field Technicians; A Learning Experience for Everyone Involved*; Proceedings - NCBC 2009)
  - Various commercial and process projects

Commissioning Process Goals

New Construction

- Verify:
  - Installed performance
  - Design intent achieved
  - Enable persistence
    - Documentation
      - Commissioning record
      - System Manual
    - Train the staff
- Try not to go crazy
- Have fun

Retrocommissioning* (MBCx program context)

- Develop facility baselines
- Identify and assess energy efficiency opportunities
- Coordinate with the Owner to implement improvements
- Verify goals are achieved
- Enable persistence
  - Documentation
    - Pre and post baseline reports
    - Train the staff
- Have Fun

A.K.A. Existing Building Commissioning, EBCx, RCx, Recommissioning, Monitoring Based Commissioning, Building Tune-up, and, when I first started, operating the building properly

Typical Issues

Cx/EBCx

- Access/Serviceability
- Occupant satisfaction
- Installation does not comply with Manufacturer or industry standards
- Implementation of complex technology difficult to achieve in real world environments
- Installation does not reflect design intent
- Integration
  - Optional/2nd party equipment
  - Other HVAC processes
  - Control systems
- Persistence

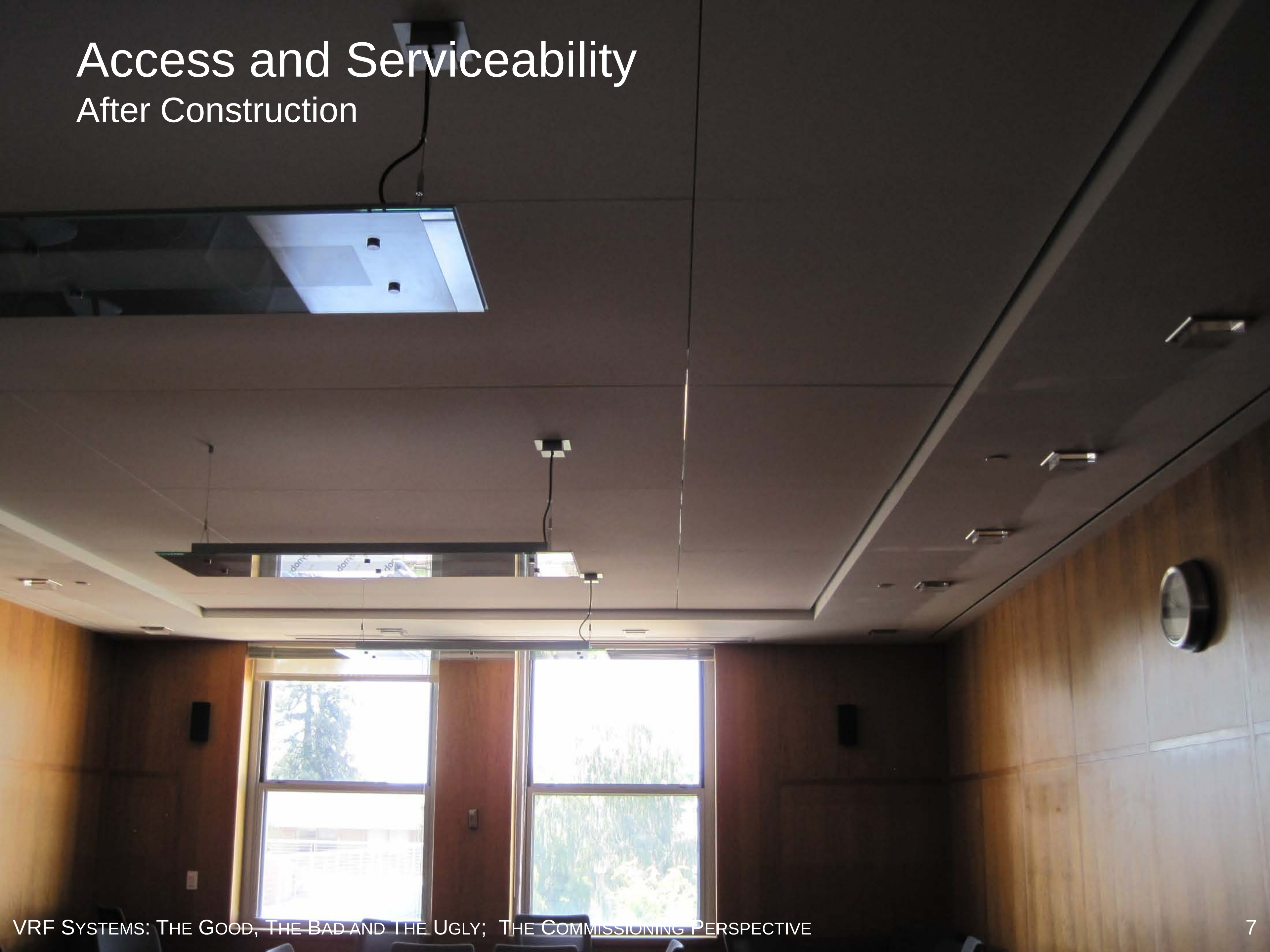
VRF Experience to Date

- Access/Serviceability
- Occupant satisfaction
- Installation does not comply with Manufacturer or industry standards
- ~~Implementation of complex technology difficult to achieve in real world environments~~
- Installation does not reflect design intent
- Integration
  - Optional/2nd party equipment
  - Other HVAC processes
  - Control systems
- Persistence

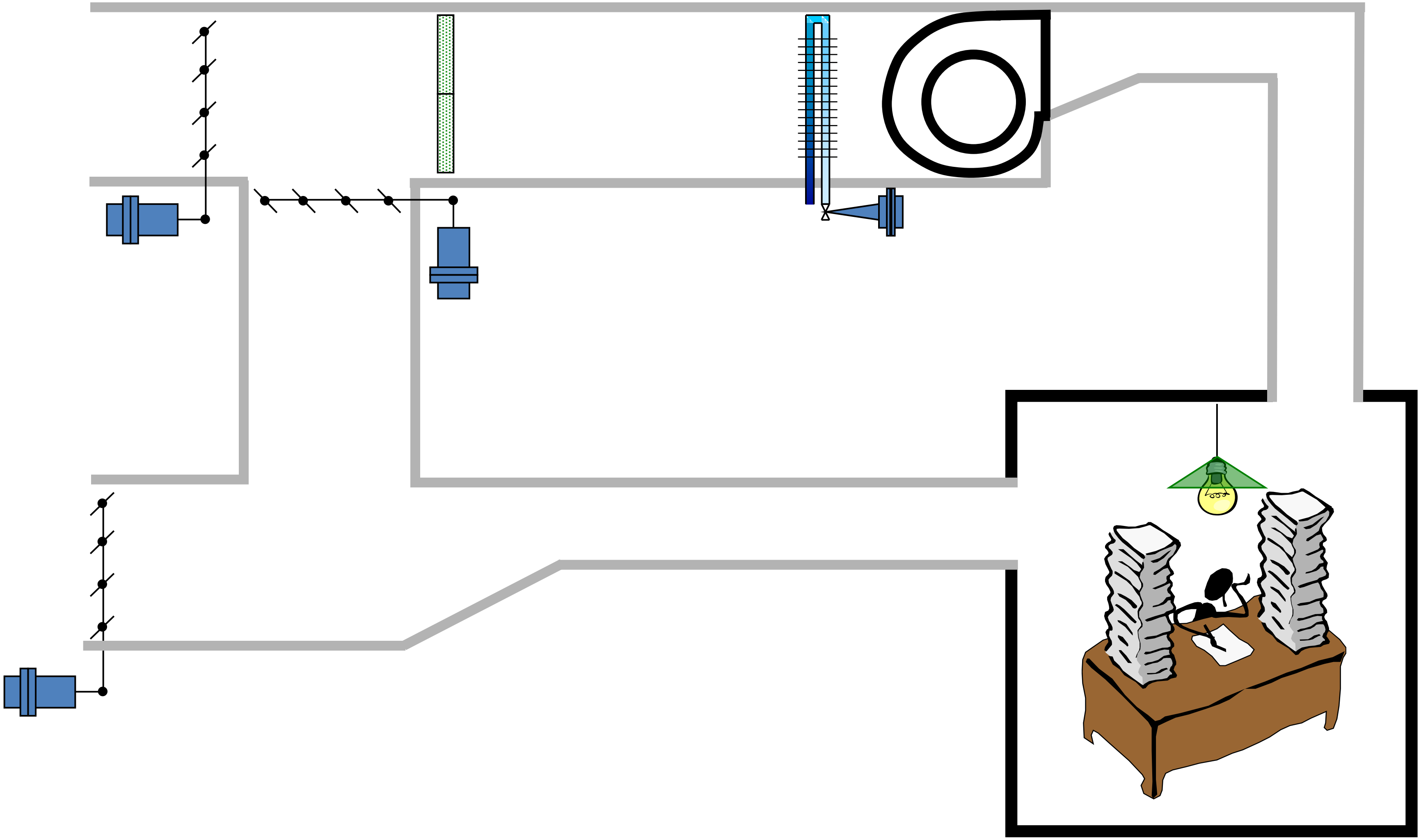
Access and Serviceability

During Construction

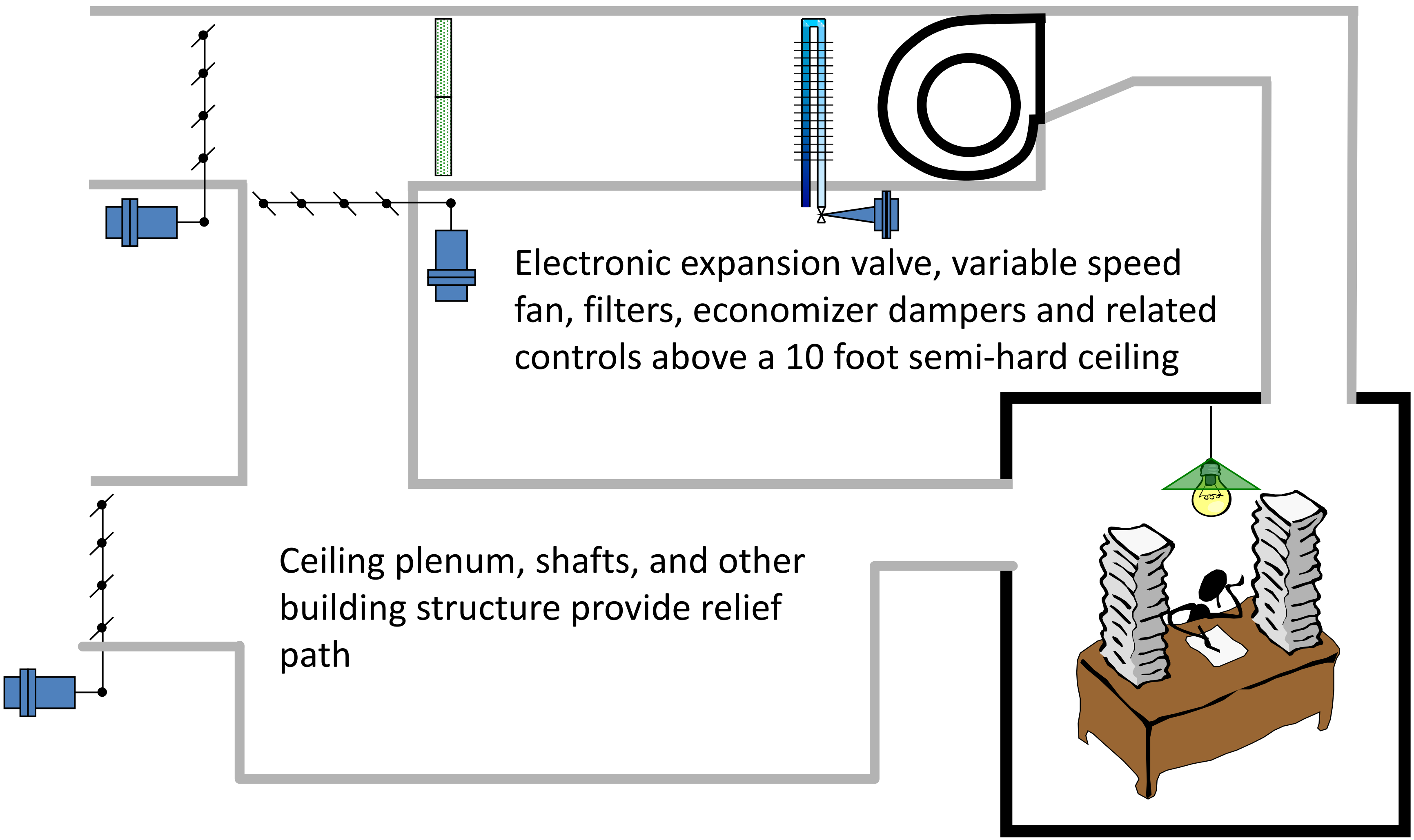
Access and Serviceability
After Construction



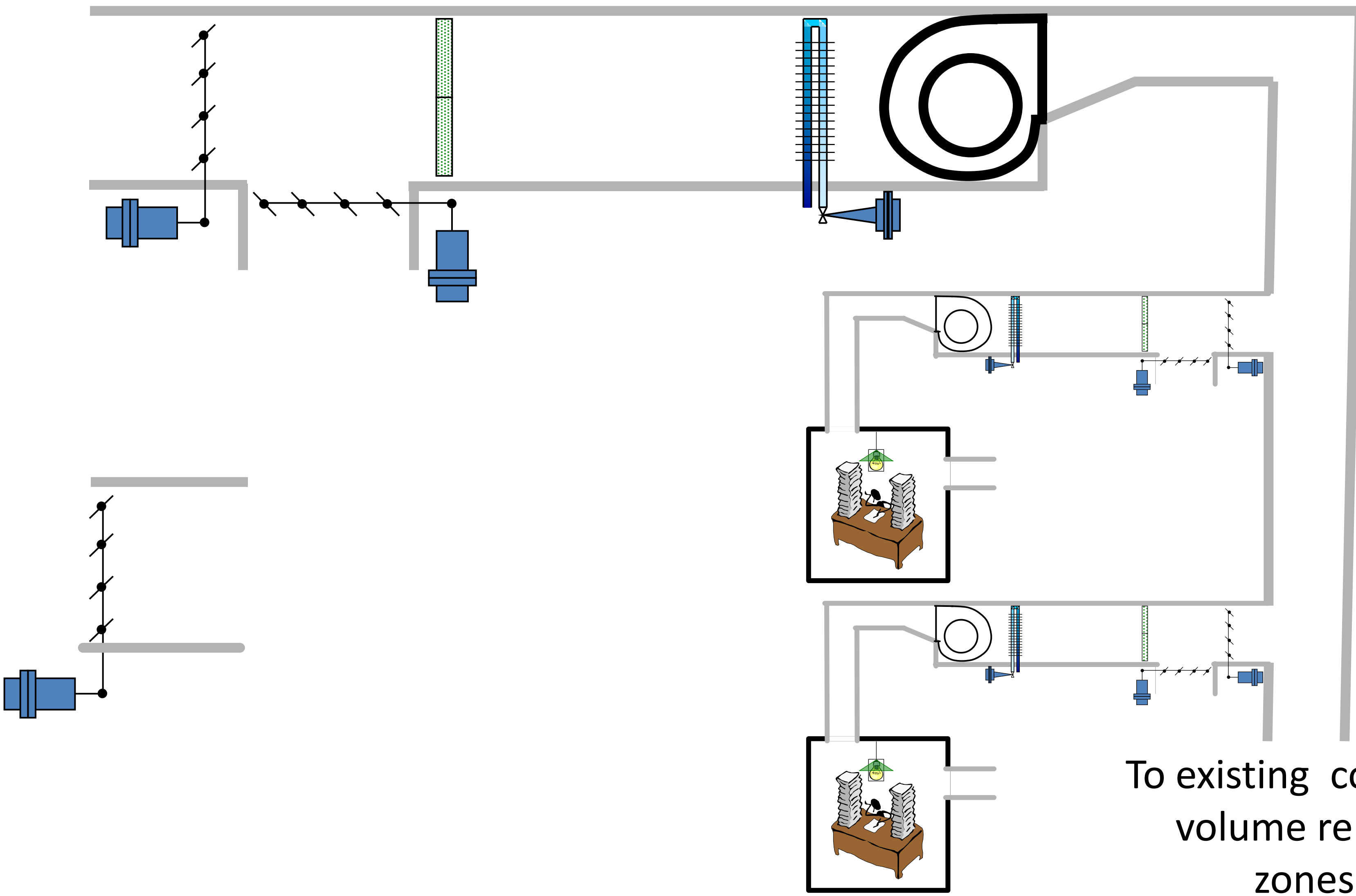
Simple Constant Volume AHU System Diagram



VRF System Diagram

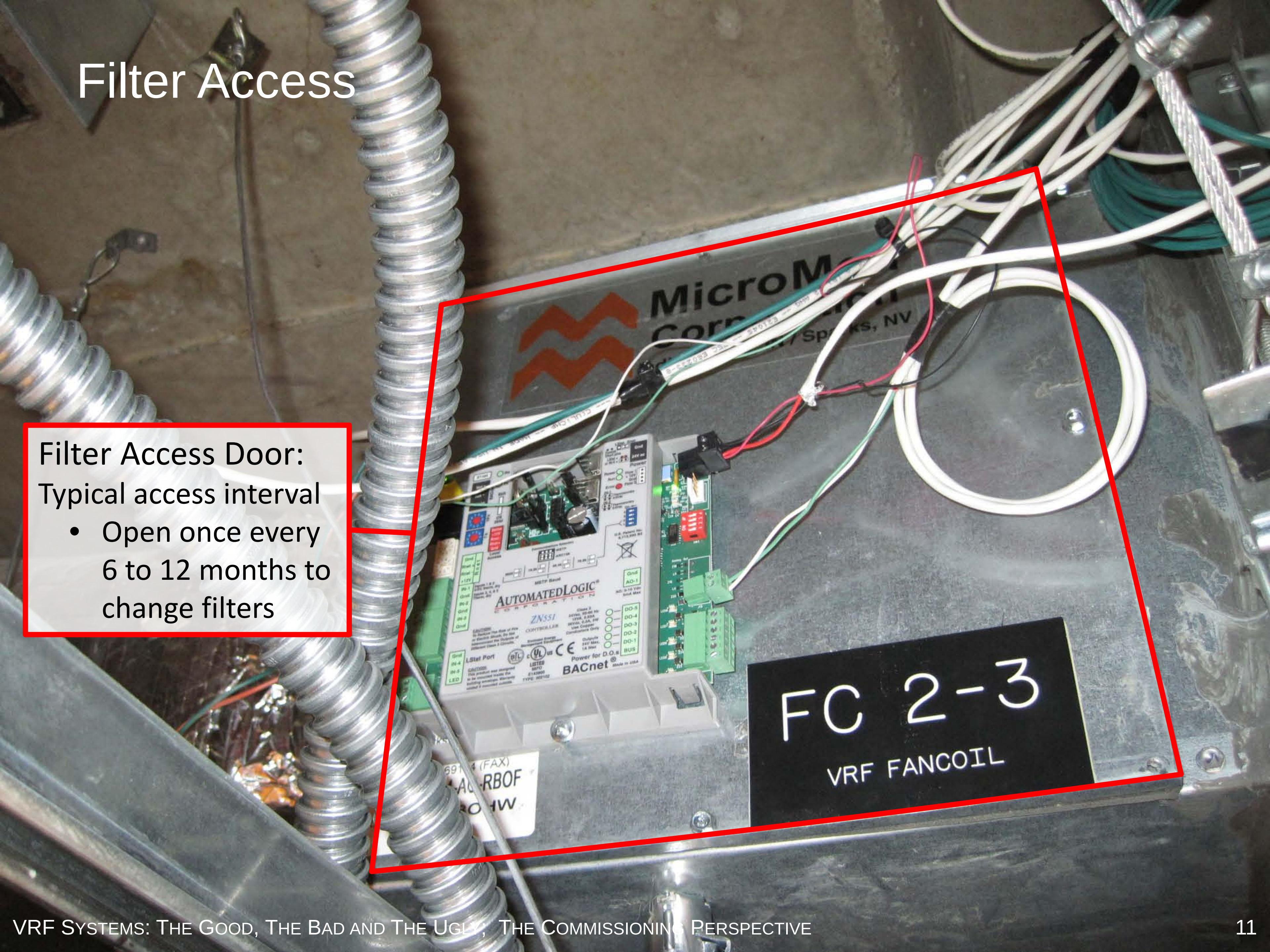


The Actual VRF System Diagram



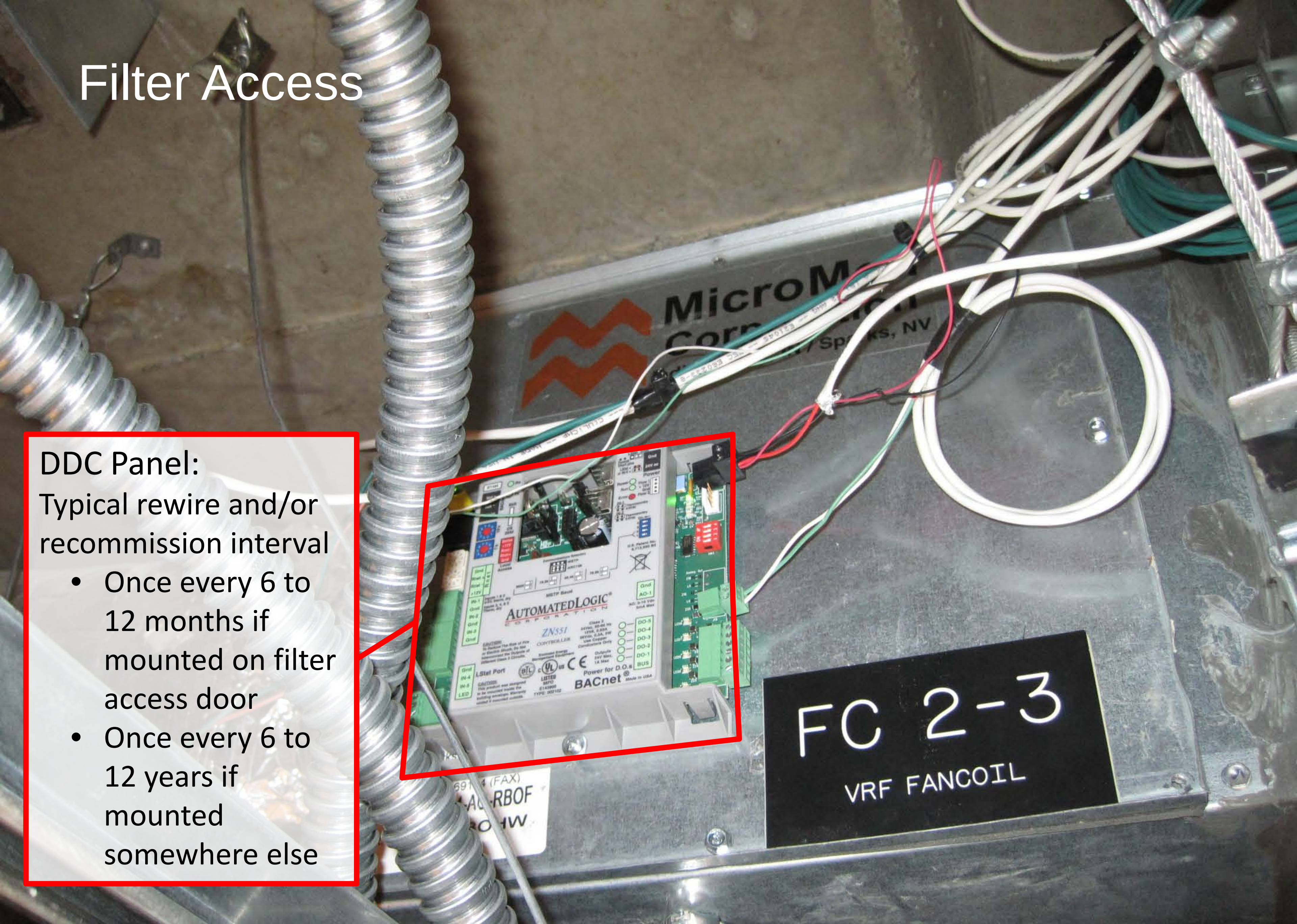
To existing constant volume reheat zones

Filter Access



Filter Access Door:
Typical access interval
- Open once every 6 to 12 months to change filters

Filter Access



DDC Panel:

Typical rewire and/or recommission interval

- Once every 6 to 12 months if mounted on filter access door
- Once every 6 to 12 years if mounted somewhere else

Macromedia Flash Player 8

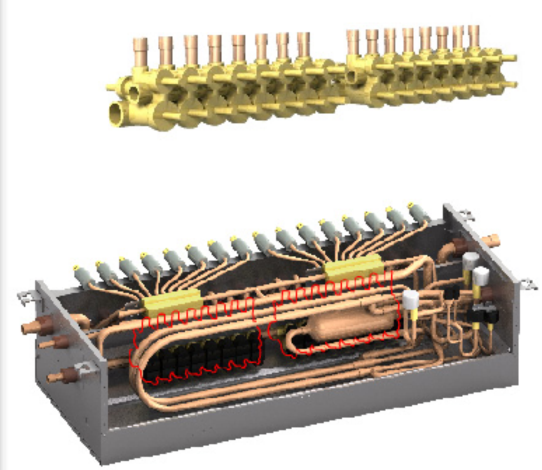
File View Control Help

Branch Controller Technology

http://www.mylinkdrive.com/CityMulti/Software/CM_Refrigerant_Flow/

MITSUBISHI
HVAC Advanced Products Division

R2 Series Indoor Section



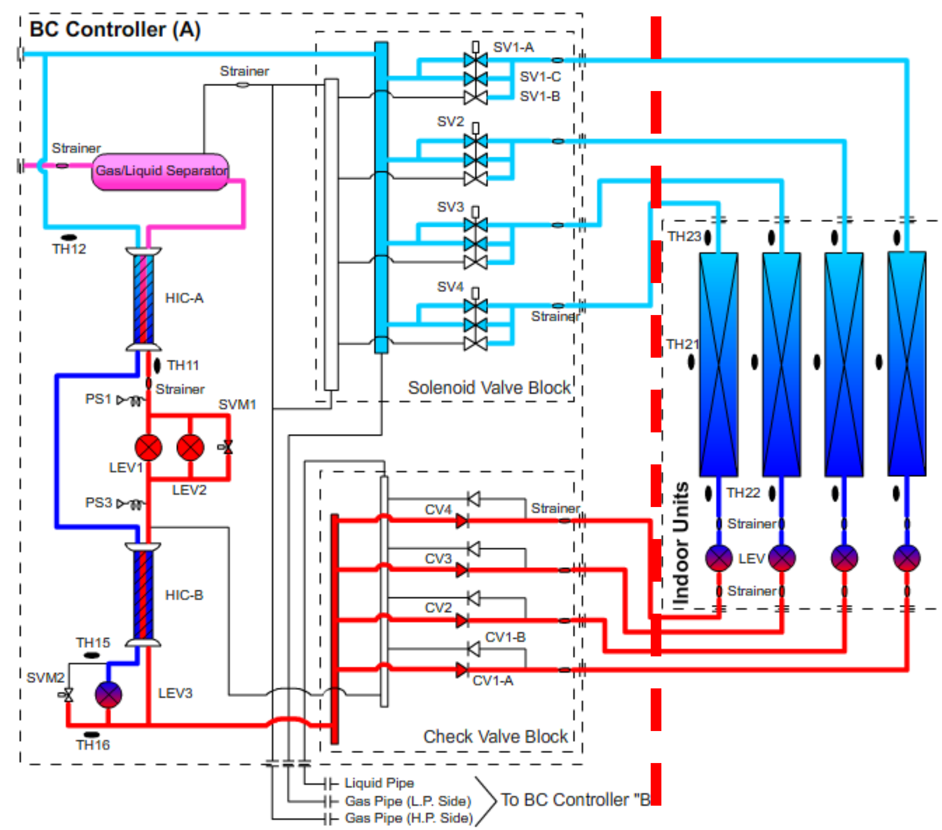
Solenoid Valve Block

(BC Controller)

The BC Controller solenoid valve block, as its name suggests, is comprised of a series of solenoid valves used to control refrigerant flow through each individual indoor circuit based on the operational mode selected for that indoor unit.

		Mode			
		Cooling	Heating	Stopped	Defrost
Port	SV_A	ON	OFF	OFF	OFF
	SV_B	OFF	ON	OFF	OFF
	SV_C	ON	OFF	OFF	OFF

Image courtesy Mitsubishi Refrigerant Flow Demonstrator; Used with Permission



Superheated Discharge Gas
Saturated High-pressure Gas
Subcooled Liquid
Saturated Low-pressure Liquid
Superheated Suction Gas
Compressor Oil

MENU

Branch Controller Technology

http://www.mylinkdrive.com

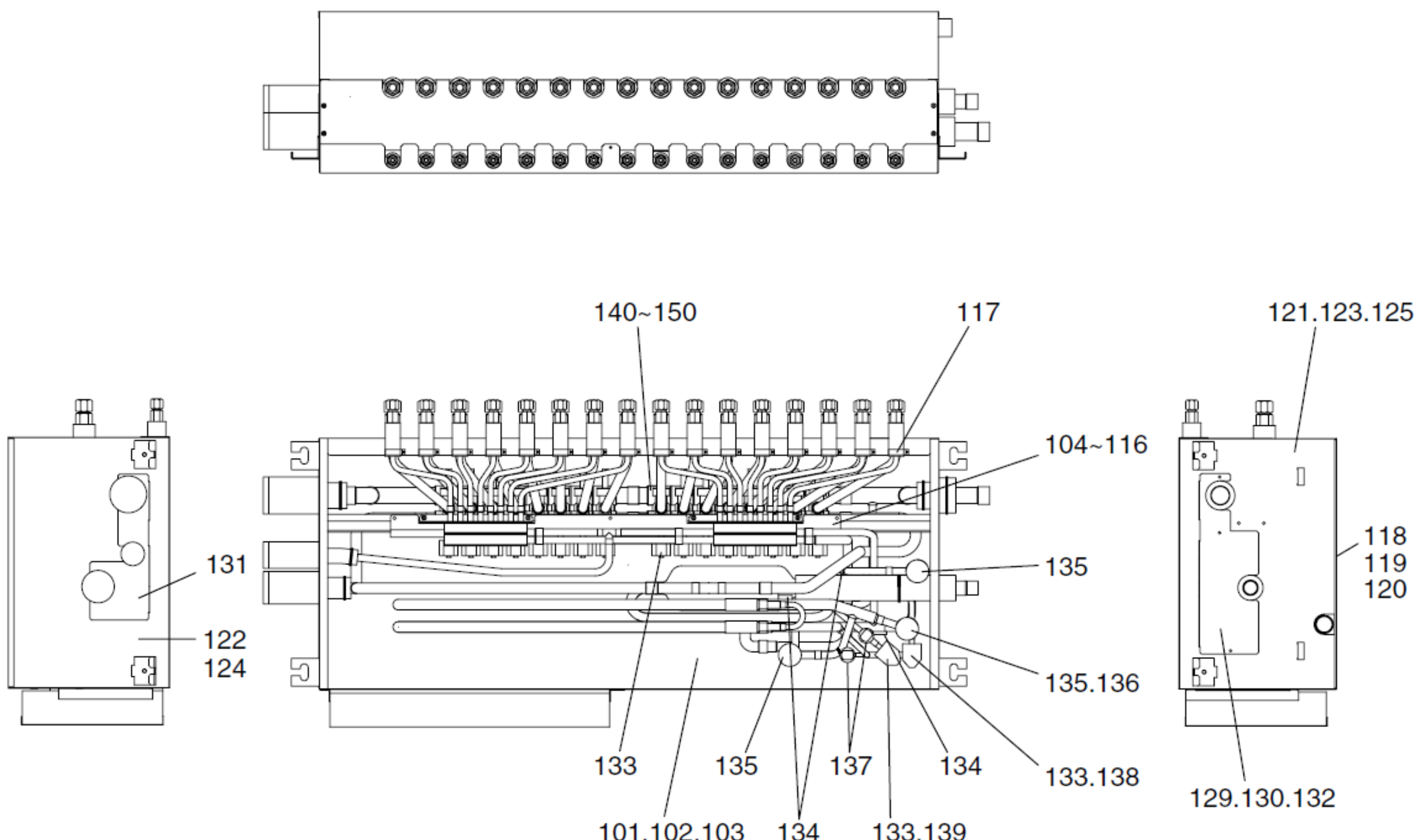


Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

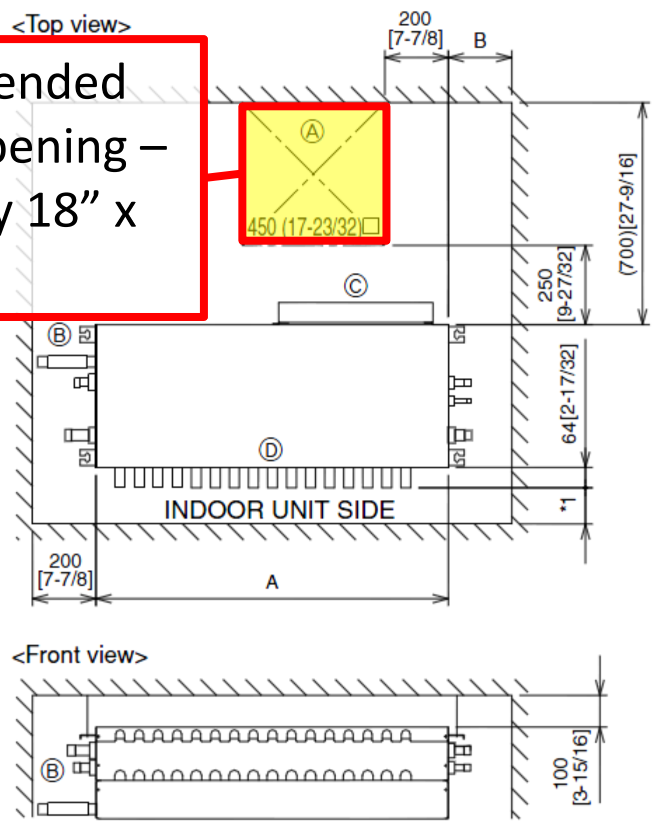
GB

2.3. Securing installation and service space

1. For hanging from the ceiling
(This is a reference view showing the least installation space.)

[Fig. 2.3.1]

(Unit: mm [in])



Recommended access opening – nominally 18” x 18”

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

Ⓐ Inspection hole
Ⓑ On the side of outdoor unit piping
Ⓒ Control box
Ⓓ On the side of indoor unit piping

Ⓒ Indoor unit Ⓓ
Ⓔ Less than H=50 m [164 ft] (when the
Ⓕ Less than H1=40 m [131 ft] (when th
Ⓖ Twinning pipe (for Y Series) CMY-Y1
Ⓗ Combined pipe (CMY-R160-J: optior
... ft] Ⓙ
branch hole
an 30 (but sam
9 ft] (10 m [32
9 ft]

Small to medium technical person - 20”

	Between indoor units and BC controller	
Difference of elevation	Between indoor and outdoor units	Above outdoor unit
		Below outdoor unit
	Between indoor units and BC controller	
	Between indoor units	

8.26 x 11.69 in

Branch Controller Installed Location

Branch Controller Installed Location

Branch Controller Installed Location

PURY,PUHY-P72~234TGMU-A_Service_Manual.pdf - Adobe Acrobat

Branch Controller Service Procedures

(1) Service panel

*Special care must be taken when replacing heavy parts.

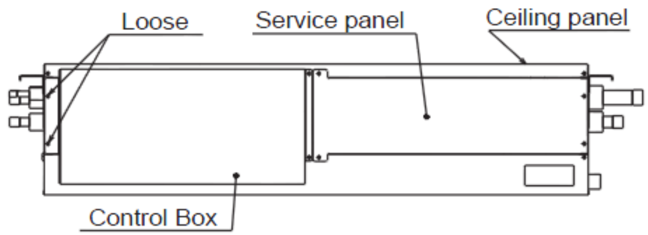
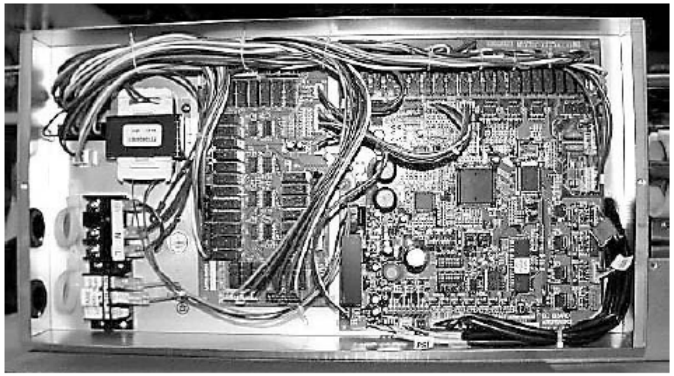
Work procedure	Explanatory figure
1. Remove 2 lock nuts on the control box, loosen 2 lock nuts, and remove the control box. 2. Remove 4 fixing screws on the service panel, and remove the service panel. 3. Remove 9 machine screws on the ceiling panel, and remove the ceiling panel.	

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

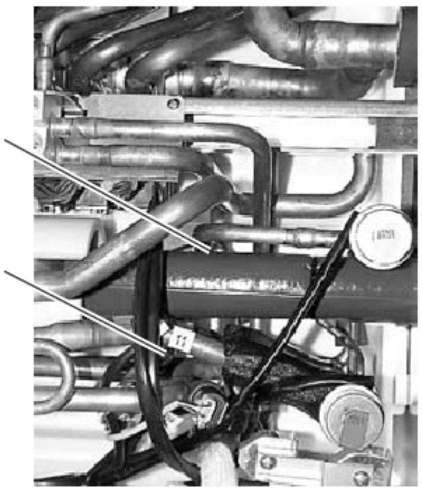
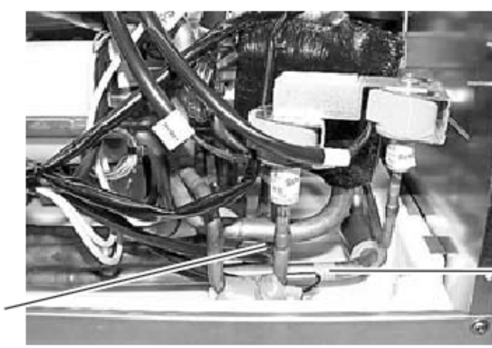
(2) Control box

Work procedure	Explanatory figure
1. To check the inside of the control box, remove 2 lock nuts on the control box cover. (1) Check the terminal connection of the power wire or of the transmission line. (2) Check the transformer. (3) Check the address switch. 2. When the control board is replaced, the followings must be noted. (1) Check that the board type is NU-G,NU-GA, or NU-GB. (2) Check that the wire or the connector is not incorrectly connected, not disconnected or not loose. Note: It is not required to remove 2 fixing screws on the control box when checking the inside.	 CMB-1016NU-G, 1016NU-GA

Branch Controller Service Procedures

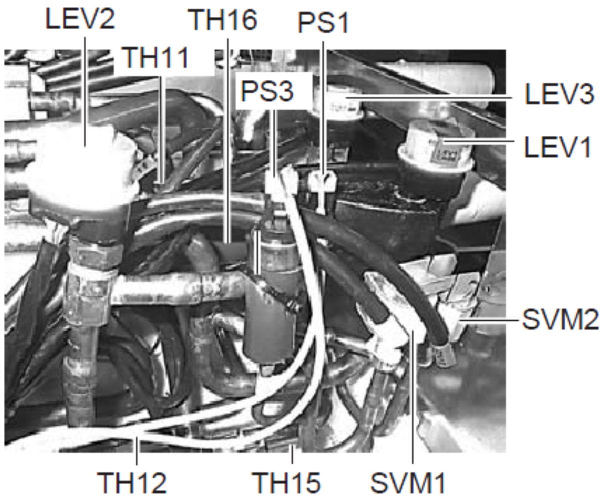
(3) Thermistor (liquid pipe/gas pipe temperature detection)

*Special care must be taken when replacing heavy parts.

Work procedure	Explanatory figure
1. Remove the service panel. (1) For TH11, TH12, and TH15, refer to (1)-1.2. (2) For TH16, refer to (1)-1.2.3. 2. Remove the lead wire of the piping sensor from the control board. (1) TH11,TH12 (CN10) (2) TH15,TH16 (CN11) 3. Pull out the temperature sensor from the temperature sensor housing, and replace the temperature sensor with the new one. 4. Connect the lead wire of the temperature sensor securely on the control board.	  CMB-1016NU-GA

Branch Controller Service Procedures

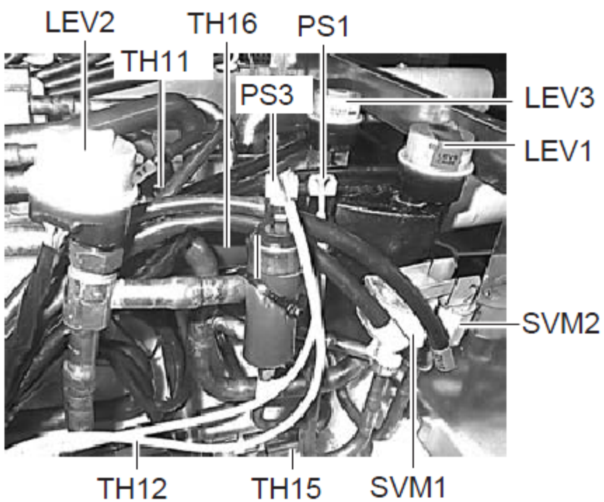
(4) Pressure sensor

Work procedure	Explanatory figure
1. Remove the service panel. (1) For the pressure sensors PS1 and PS3, refer to (1)-1.2. 2. Remove the pressure sensor connector in trouble from the control board, and insulate the connector. (1) Liquid-side pressure sensor (CNP1) (2) Intermediate-part pressure sensor (CNP3) 3. Attach a new pressure sensor to the place which is shown in the figure, and insert the connector to the control board. Note: When gas leaks from the pressure sensor, repair the leak, and follow the instructions above if re-quired.	 *For NU-G-type, there is no SVM2. CMB-1016NU-GA

Branch Controller Service Procedures

IX Troubleshooting]

(5) LEV

Work procedure	Explanatory figure
1. Remove the service panel.(Refer to (1)-1.2.3.) 2. Replace the LEV in trouble. Note: Secure enough service space in the ceiling for welding operation, and conduct the work carefully.If required, dismount the unit from the ceiling, and conduct the work. *Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission*	 *For NU-G-type, there is no SVM2. CMB-1016NU-GA

(6) Solenoid valve

*Special care must be taken when replacing heavy parts.

Work procedure	Explanatory figure
1. Remove the service panel.(Refer to (1)-1.2.3.) 2. Remove the connector of the solenoid valve in trouble.	

Branch Controller Service Procedures

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

Typical service welding equipment

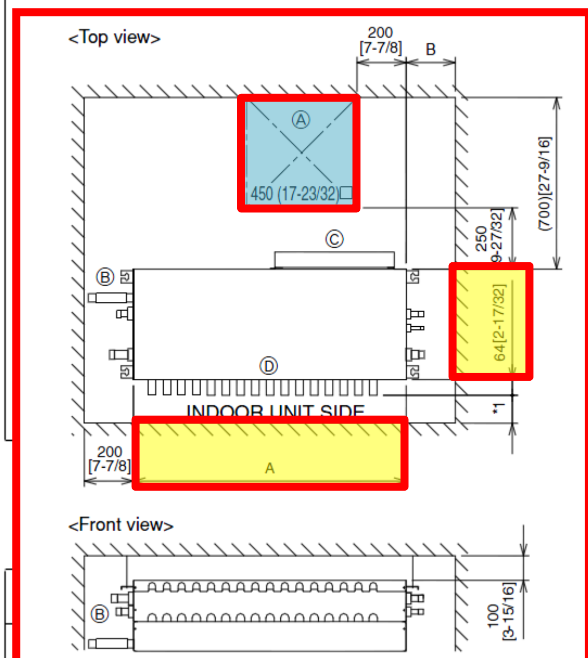
Branch Controller Service Procedures

PURY,PUHY-P72~234TGMU-A_Service_Manual.pdf - Adobe Acrobat

[IX Troubleshooting]

(5) LEV

Work procedure
1. Remove the service panel.(Refer to (1)-1.2.3.) 2. Replace the LEV in trouble. Note: Secure enough service space in the ceiling for welding operation, and conduct the work carefully.If required, dismount the unit from the ceiling, and conduct the work.



...ction;

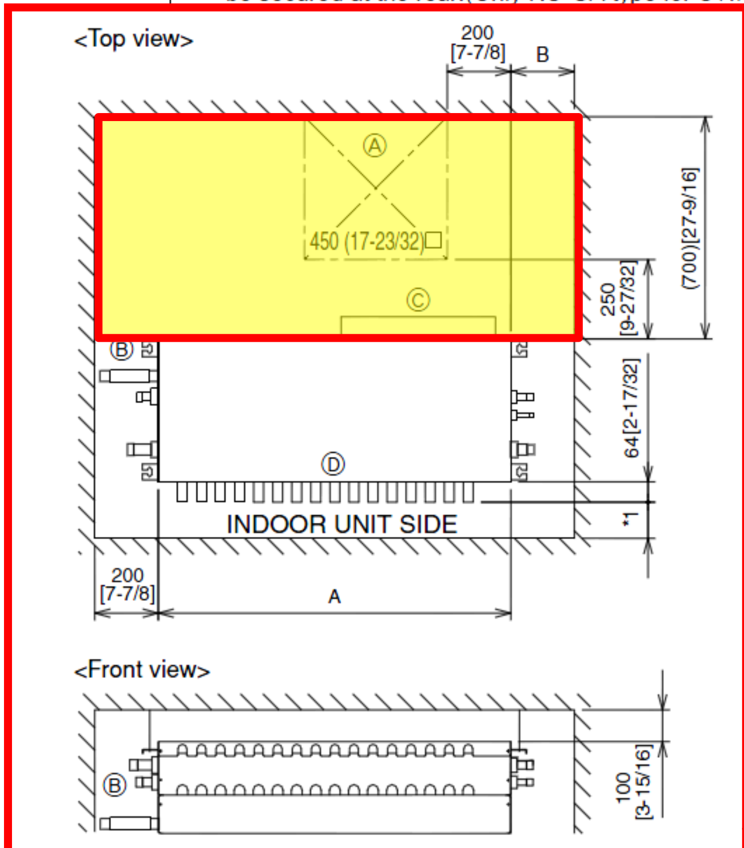
2.3.)

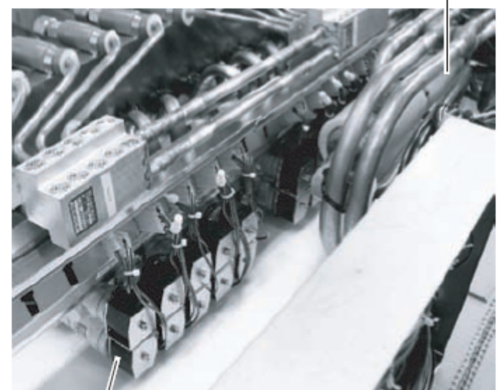
2. Remove the connector of the solenoid valve in trouble.

Branch Controller Service Procedures

*Special care must be taken when replacing heavy parts.

Work procedure	Explanatory figure
1. Remove the service panel.(Refer to (1)-1.2.3.) 2. Remove the connector of the solenoid valve in trouble. 3. Remove the solenoid valve coil. (1) For the solenoid valve coil of SVA, SVB, or SVM1, 2, can be serviced from the inspection door is possible. For SVC, however, remove the rear panel (4 machine screws) to replace the coil if enough service space can be secured at the rear.(Only NU-GA type for SVM 2)	





CMB-1016NU-G

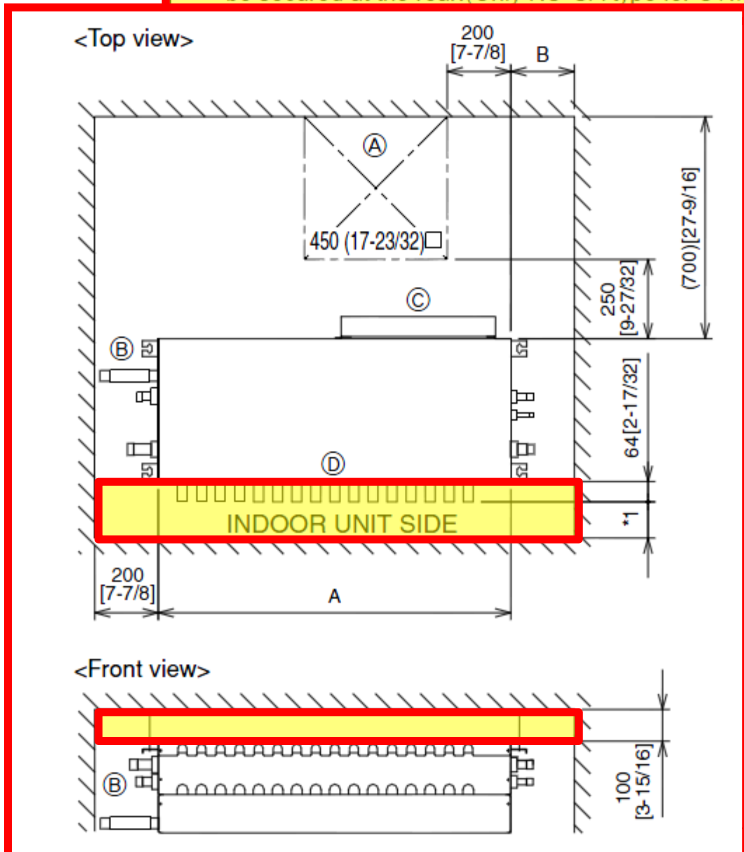
CMB-1016NU-GA

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

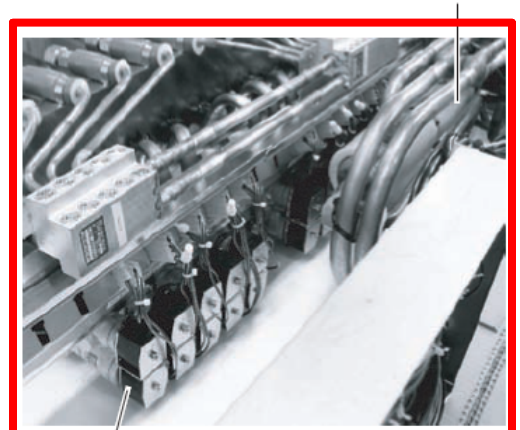
Branch Controller Service Procedures

*Special care must be taken when replacing heavy parts.

Work procedure	Explanatory figure
1. Remove the service panel.(Refer to (1)-1.2.3.) 2. Remove the connector of the solenoid valve in trouble. 3. Remove the solenoid valve coil. (1) For the solenoid valve coil of SVA, SVB, or SVM1, 2, can be serviced from the inspection door is possible. For SVC, however, remove the rear panel (4 machine screws) to replace the coil if enough service space can be secured at the rear.(Only NU-GA type for SVM 2)	Double-pipe heat exchanger CMB-1016NU-G Solenoid valve CMB-1016NU-GA



Double-pipe heat exchanger



CMB-1016NU-G

Solenoid valve

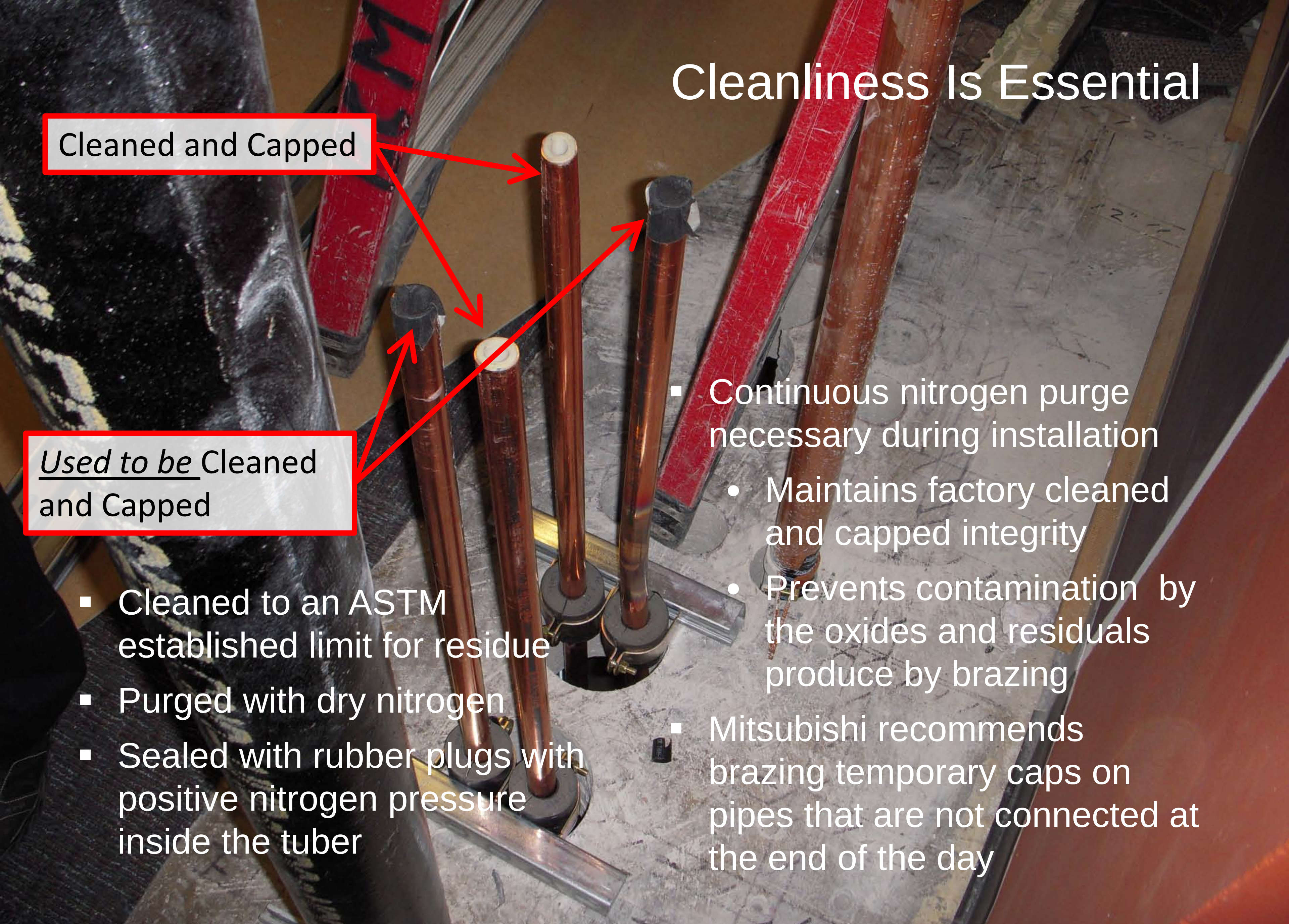
CMB-1016NU-GA

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

Installation Practices

- Refrigerant piping installation practice critical to short and long term system integrity
  - General requirements no different from those employed with any built up refrigeration system
  - Details associated with R410 systems may vary from standard practice in the field at this point in time

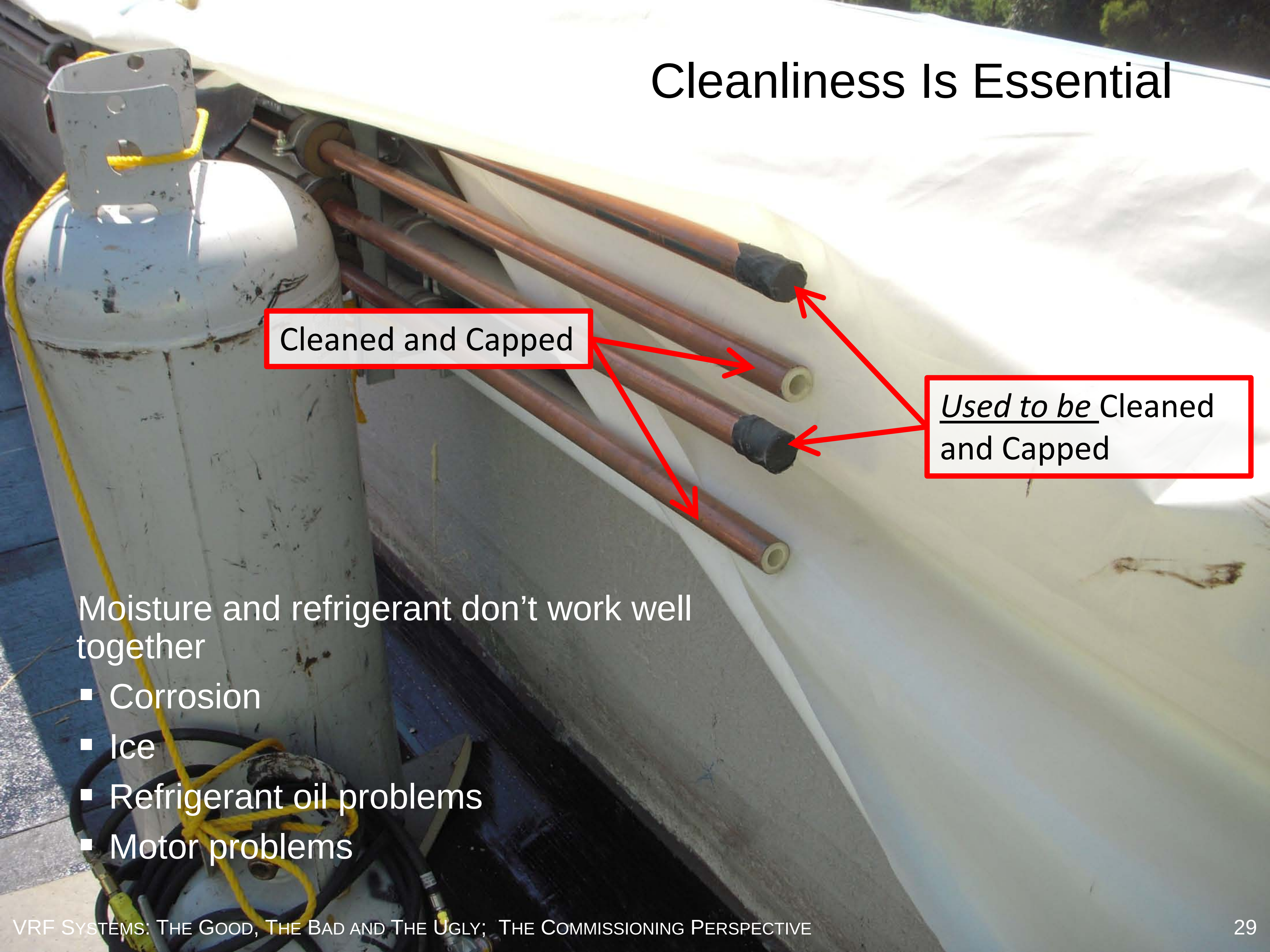
Cleanliness Is Essential



- Cleaned to an ASTM established limit for residue
- Purged with dry nitrogen
- Sealed with rubber plugs with positive nitrogen pressure inside the tuber

- Continuous nitrogen purge necessary during installation
  - Maintains factory cleaned and capped integrity
  - Prevents contamination by the oxides and residuals produce by brazing
- Mitsubishi recommends brazing temporary caps on pipes that are not connected at the end of the day

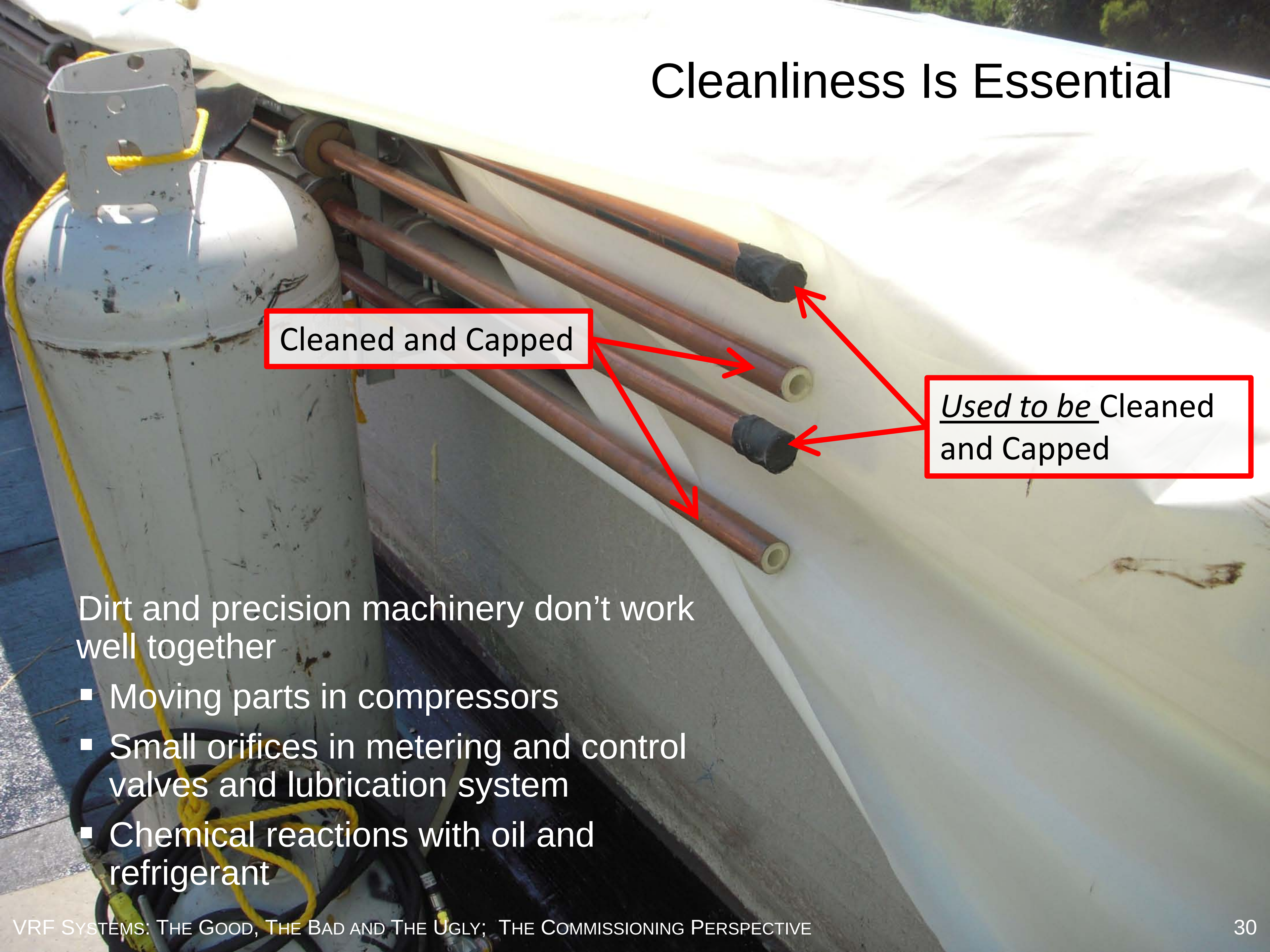
Cleanliness Is Essential



Moisture and refrigerant don't work well together

- Corrosion
- Ice
- Refrigerant oil problems
- Motor problems

Cleanliness Is Essential



Dirt and precision machinery don't work well together

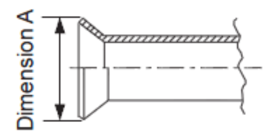
- Moving parts in compressors
- Small orifices in metering and control valves and lubrication system
- Chemical reactions with oil and refrigerant

Field Joints

- Field joints are made using a frustum of right circular cone

5. Flare processing (O-material (Annealed) only)

Pipe size (mm[in])		R410A		R22	
ø6.35	[1/4"]	9.1	[0.358]	9.0	[0.354]
ø9.52	[3/8"]	13.2	[0.520]	13.0	[0.512]
ø12.7	[1/2"]	16.6	[0.654]	16.2	[0.638]
ø15.88	[5/8"]	19.7	[0.776]	19.4	[0.764]
ø19.05	[3/4"]	24.0	[0.945]	23.3	[0.917]



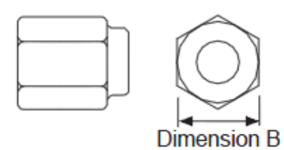
If a clutch-type flare tool is used to flare the pipes in the system using R410A, the length of the pipes must be between 1.0 and 1.5 mm. For margin adjustment, a copper pipe gauge is necessary.

6. Flare nut

Type-2 flare nuts instead of type-1 are used to increase the strength. The size of some of the flare nuts have also been changed.

Flare nut dimensions (mm[in])

Pipe size (mm[in])		B dimension (mm[in])			
		R410A		R22	
ø6.35	[1/4"]	17.0	[0.669]	17.0	[0.669]
ø9.52	[3/8"]	22.0	[0.866]	22.0	[0.866]
ø12.7	[1/2"]	26.0	[1.024]	24.0	[0.945]
ø15.88	[5/8"]	29.0	[1.142]	27.0	[1.063]
ø19.05	[3/4"]	36.0	[1.417]	36.0	[1.417]



The figures in the radial thickness column are based on the Japanese standards and provided only as a reference. Use pipes that meet the local standards.

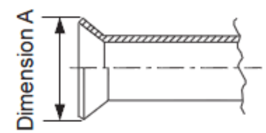
Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

Field Joints

- Field joints are made using a 45°SAE Flare joint

5. Flare processing (O-material (Annealed) only)

Pipe size (mm[in])		R410A		R22	
ø6.35	[1/4"]	9.1	[0.358]	9.0	[0.354]
ø9.52	[3/8"]	13.2	[0.520]	13.0	[0.512]
ø12.7	[1/2"]	16.6	[0.654]	16.2	[0.638]
ø15.88	[5/8"]	19.7	[0.776]	19.4	[0.764]
ø19.05	[3/4"]	24.0	[0.945]	23.3	[0.917]



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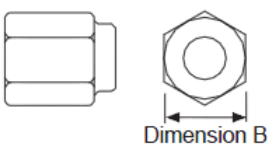
ø15.88	[5/8"]	29.0	[1.142]	27.0	[1.063]
ø19.05	[3/4"]	36.0	[1.417]	36.0	[1.417]



The figures in the radial thickness column are based on the Japanese standards and provided only as a reference. Use pipes that meet the local standards.

Operating Pressures

Refrigerant	Low Side	High Side
R22	55-70 psig	180 - 260 psig
R410	95 - 135 psig	305 - 410 psig

Image courtesy Mitsubishi PRUY Service Instruction; Used with Permission

Field Joints

1. Determine the increase in seating surface for different flare dimensions
2. S = π x (R_1 + R_2) x s

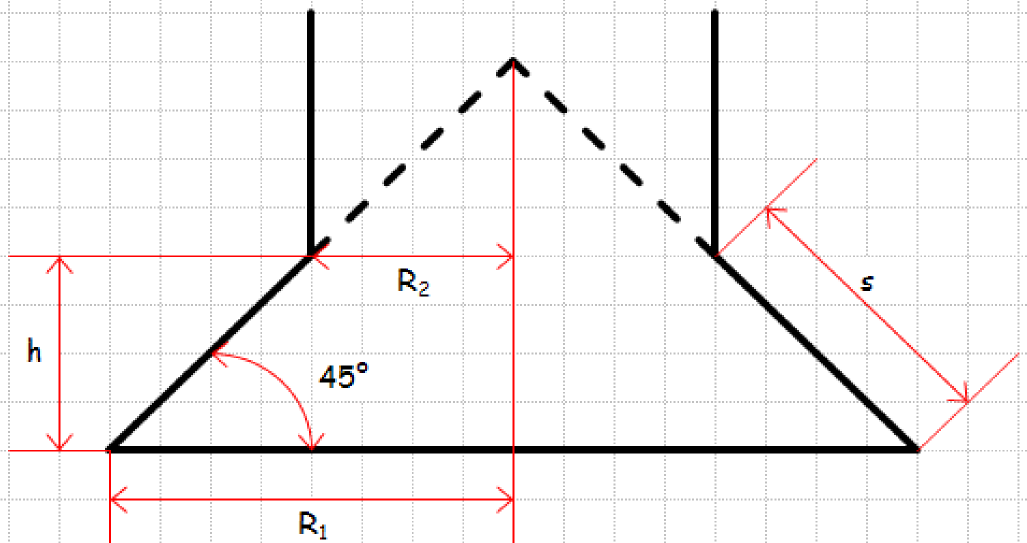
   Where, for a Frustrum of a Right Circular Cone:

   S = Lateral surface area

   R_1 = Radius of lower base

   R_2 = Radius of upper base

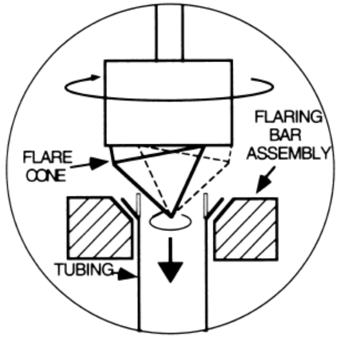
   s = Slant height
3. s = $((R_1-R_2)^2 + h_2)^{1/2}$



Field Joints

For nominal 3/8" tube								
R410A Application					**R22 Application**			
Flare dimension -	16.60	mm			Flare dimension -	16.20	mm	
Tube dimension -	12.70	mm			Tube dimension -	12.70	mm	
Difference -	3.90	mm			Difference -	3.50	mm	
Half of difference -	1.95	mm			Half of difference -	1.75	mm	
Length of flare (height of frustrum) -	1.95	mm			Length of flare (height of frustrum) -	1.75	mm	
Slant height -	2.40	mm			Slant height -	2.19	mm	
Area of flare -	221	sq mm			Area of flare -	199	sq mm	
Difference -	21.60	sq mm	=	10.8%				
For nominal 1/2" tube								
R410A Application					**R22 Application**			
Flare dimension -	19.70	mm			Flare dimension -	19.40	mm	
Tube dimension -	15.88	mm			Tube dimension -	15.88	mm	
Difference -	3.82	mm			Difference -	3.52	mm	
Half of difference -	1.91	mm			Half of difference -	1.76	mm	
Length of flare (height of frustrum) -	1.91	mm			Length of flare (height of frustrum) -	1.76	mm	
Slant height -	2.36	mm			Slant height -	2.20	mm	
Area of flare -	264	sq mm			Area of flare -	244	sq mm	
Difference -	19.24	sq mm	=	7.9%				
For nominal 3/4" tube								
R410A Application					**R22 Application**			
Flare dimension -	24.00	mm			Flare dimension -	23.30	mm	
Tube dimension -	19.50	mm			Tube dimension -	19.50	mm	
Difference -	4.50	mm			Difference -	3.80	mm	
Half of difference -	2.25	mm			Half of difference -	1.90	mm	
Length of flare (height of frustrum) -	2.25	mm			Length of flare (height of frustrum) -	1.90	mm	
Slant height -	2.70	mm			Slant height -	2.35	mm	
Area of flare -	370	sq mm			Area of flare -	316	sq mm	
Difference -	53.93	sq mm	=	17.1%				

Flaring Tools; They're Not All Created Equal

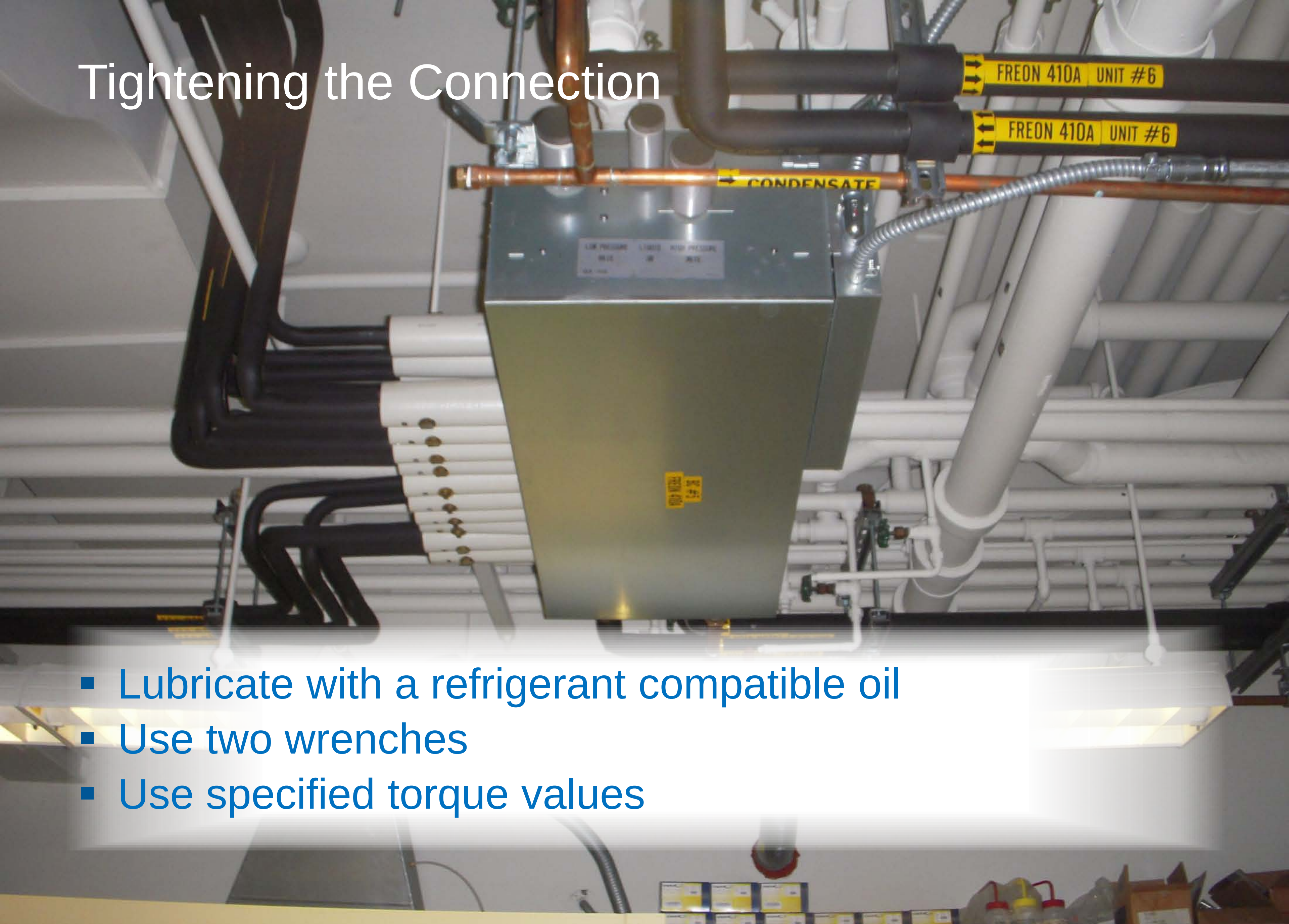


:centrically Mounted Flare Cone

- Conventional flaring tools "press" the flare onto the end of the tube
- Recommended flaring tool rolls the flare onto the end of the tube
- Either way:
  - Metal to metal sealing mechanism
  - Lubricate flare before tightening

Images courtesy www.ridgid.com/; Used with Permission

Tightening the Connection



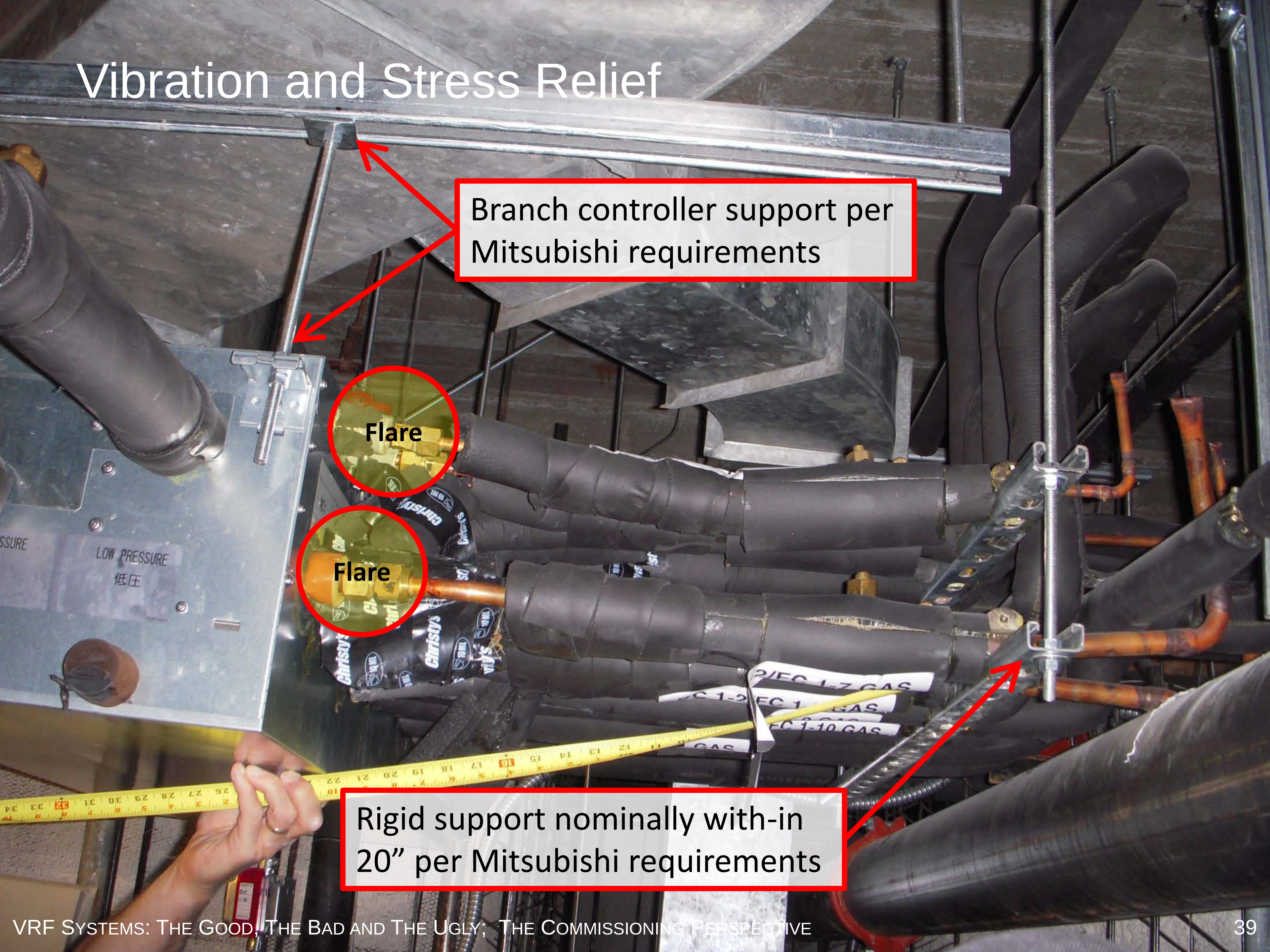
- Lubricate with a refrigerant compatible oil
- Use two wrenches
- Use specified torque values

Torque Wrenches, Flare Nut Wrench and Crow's Foot

Tightening the Connection

- Easier accomplished on the bench than in the air
- Factory line sets minimize field flares

Vibration and Stress Relief



Vibration and Stress Relief

Refrigerant Oil

- R22 systems use mineral oil as a lubricant
- R410A systems use an ester oil, either ether oil or alkylbenzene
  - Using the wrong oil can cause sludge and other problems leading to failure
  - Tools use on R22 systems can be “contaminated” with mineral oil and should not be used on R410A systems
  - Contamination can lead to sludge and other problems
  - R410 oil is an order of magnitude more hygroscopic than R22 oil

Connecting to Existing Branch Controllers

- Concern on the part of the new project contractor regarding unknown quality of the previous contractor’s work
  - Pipe installation practice
  - System evacuation and charging practice
  - Low charge in existing system due to leakage
- Near Azeotropic refrigerant compounds the problem

Azeotrope

- A mixture made up of two or more refrigerants with similar boiling points that act as a single fluid. The components of azeotropic mixtures will not separate under normal operating conditions and can be charged as a vapor or liquid

Definitions from the National Refrigerants web site; http://www.refrigerants.com/frame.htm

Near Azeotrope

- A mixture made up of two or more refrigerants with different boiling points that, when in a totally liquid or vapor state, act as one component. However, when changing from vapor to liquid or liquid to vapor, the individual refrigerants evaporate or condense at different temperatures. Near-azeotropic mixtures have a temperature glide of less than 10° F and should be charged in the liquid state to assure proper mixture (non-azeotropic) composition

Definitions from the National Refrigerants web site; http://www.refrigerants.com/frame.htm

Zeotrope

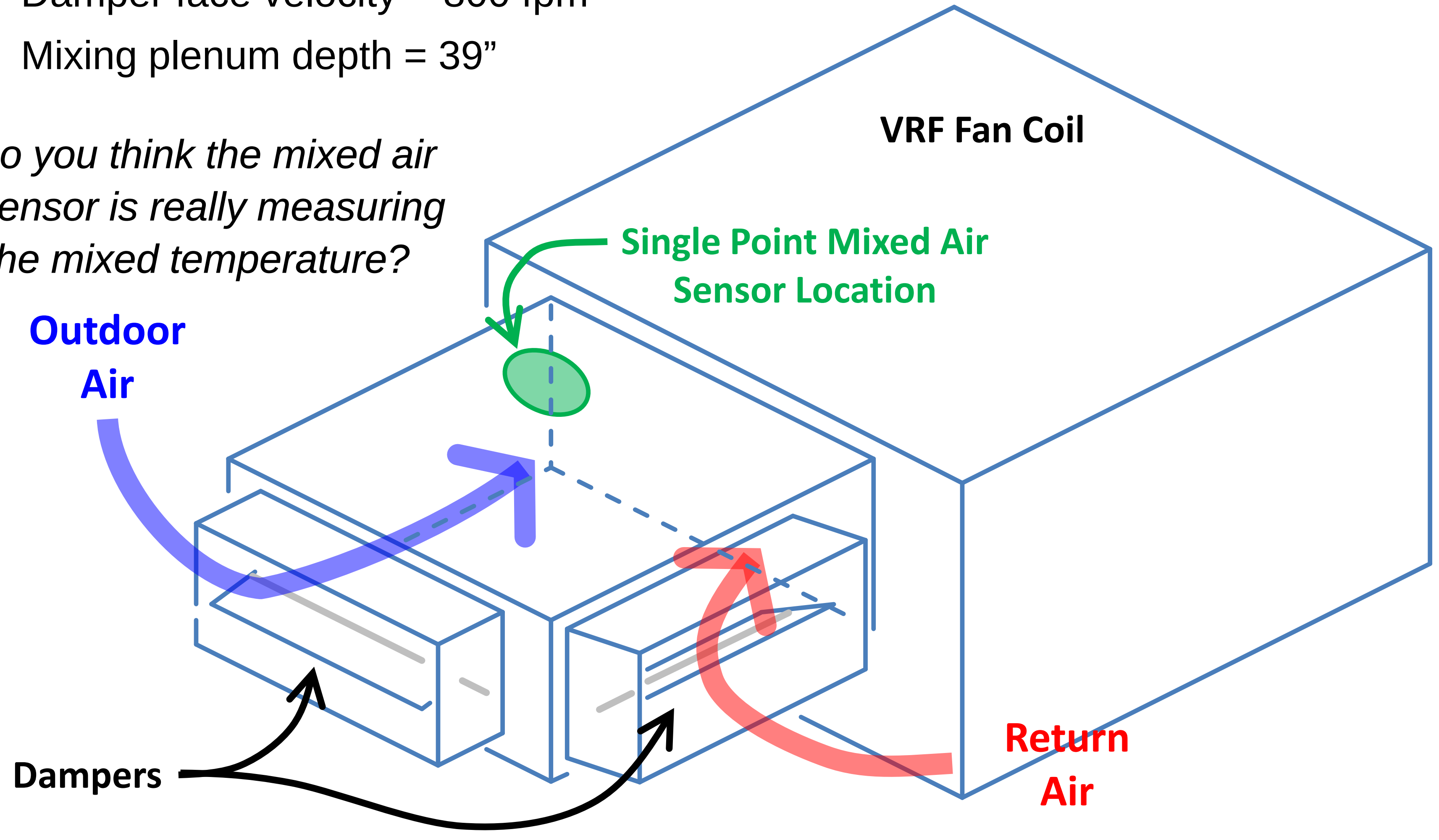
- A mixture made up of two or more refrigerants with different boiling points. Zeotropic mixtures are similar to near-azeotropic mixtures with the exception of having a temperature glide greater than 10° F. Zeotropic mixtures should be charged in the liquid state

Definitions from the National Refrigerants web site; http://www.refrigerants.com/frame.htm

Control Sensor Installation

- Damper face velocity = 800 fpm
- Mixing plenum depth = 39"

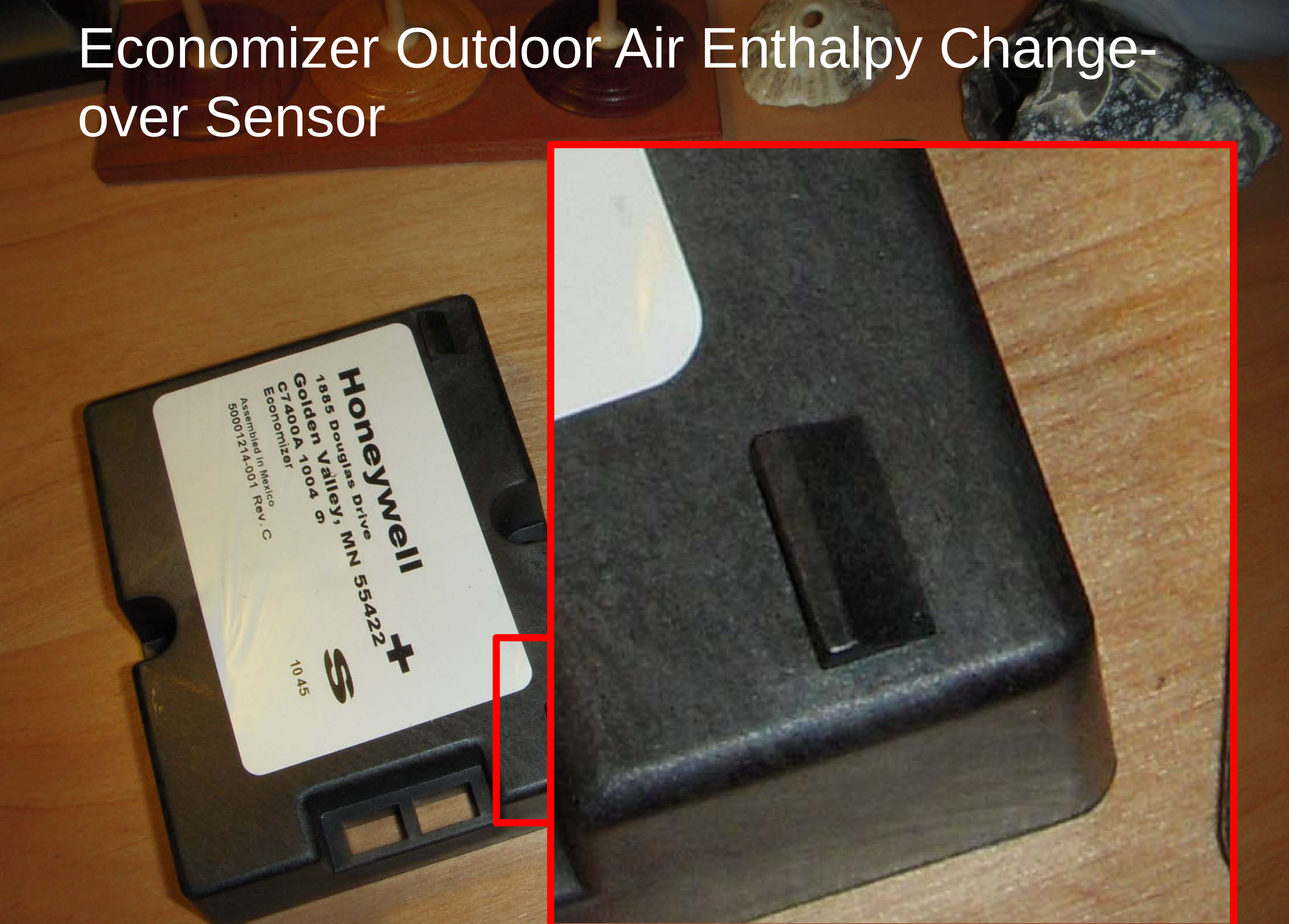
Do you think the mixed air Sensor is really measuring The mixed temperature?



Economizer Outdoor Air Enthalpy Change-over Sensor

Economizer Outdoor Air Enthalpy Change-over Sensor

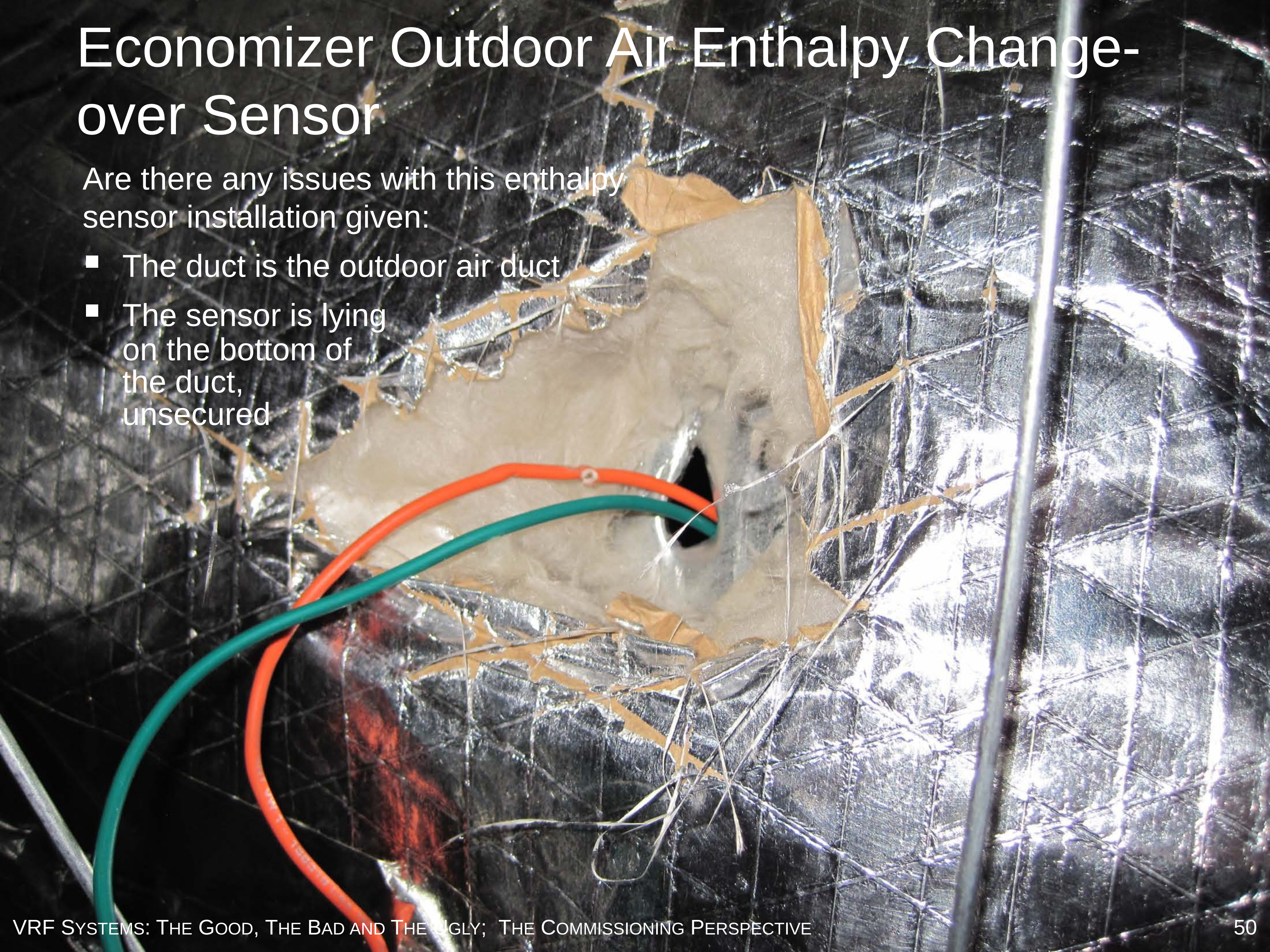
Economizer Outdoor Air Enthalpy Change-over Sensor



Economizer Outdoor Air Enthalpy Change-over Sensor

Are there any issues with this enthalpy sensor installation given:

- The duct is the outdoor air duct
- The sensor is lying on the bottom of the duct, unsecured



The Improved installation

Image courtesy Brian Nixon

The Improved installation

Image courtesy Brian Nixon

The Improved installation

Image courtesy Brian Nixon

VRF Unit Economizer Design Intent

- Provide an economizer cycle
- No mechanical cooling until the economizer is on 100% outdoor air (Code requirement; integrated economizer)
- Supplement the outdoor air cooling as required (Code requirement; integrated economizer)
- Continue to use outdoor air until the outdoor air is not suitable for cooling (Code requirement; integrated economizer)
- Use minimum outdoor air if the outdoor air enthalpy is not suitable for cooling (Code requirement; integrated economizer)
- Do not heat until the economizer is on minimum outdoor air (i.e. no simultaneous heating and cooling)
- Position to full return air if the VRF system is off (critical given the OA source)
- Use no outdoor air in warm-up mode if the space is not occupied
- Use outdoor air in the cool-down mode only if outdoor air is suitable for cooling
- Minimum outdoor air flow matches contract document requirements for minimum occupancy and maximum occupancy
- The demand controlled ventilation system can over-ride the temperature based control of the economizer cycle if necessary to maintain adequate ventilation.

Design Intent Documentation

- Required accessory on the VRF unit schedule
- Code compliance required
- Economizer supplier uses Honeywell W7212 which:
  - Can perform integrated economizer cycle (but also can do a non-integrated economizer cycle
  - Can do warm-up/cool down if configured properly
  - Can close the dampers when the system is off if configured properly
  - Can do either/or demand controlled ventilation cycle
    - Minimum occupancy air flow if CO_2 below threshold
    - Maximum occupancy air flow if CO_2 above threshold

Design Intent Documentation vs. Intent

Covered by Documents

- Provide air economizer cycle

Covered by Code

- No mechanical cooling until the economizer is on 100% outdoor air (Code requirement; integrated economizer)

Covered by Code

- Supplement the outdoor air cooling as required (Code requirement; integrated economizer)

Covered by Code

- Continue to use outdoor air until the outdoor air is not suitable for cooling (Code requirement; integrated economizer)

Covered by Code

- Use minimum outdoor air if the outdoor air enthalpy is not suitable for cooling (Code requirement; integrated economizer)
- Do not heat until the economizer is on minimum outdoor air (i.e. no simultaneous heating and cooling)

Covered by W7212 if Implemented

- Position to full return air if the VRF system is off (critical given the OA source)

Covered by W7212 if Implemented

- Use no outdoor air in warm-up mode if the space is not occupied

Covered by W7212 if Implemented

- Use outdoor air in the cool-down mode only if outdoor air is suitable for cooling

Covered by Documents; Probably requires TAB RFI to clarify

- Minimum outdoor air flow matches control documents requirement for minimum occupancy and maximum occupancy

Covered by W7212 if Implemented

- The demand controlled ventilation system can over-ride the temperature based control of the economizer cycle if necessary to maintain adequate ventilation.

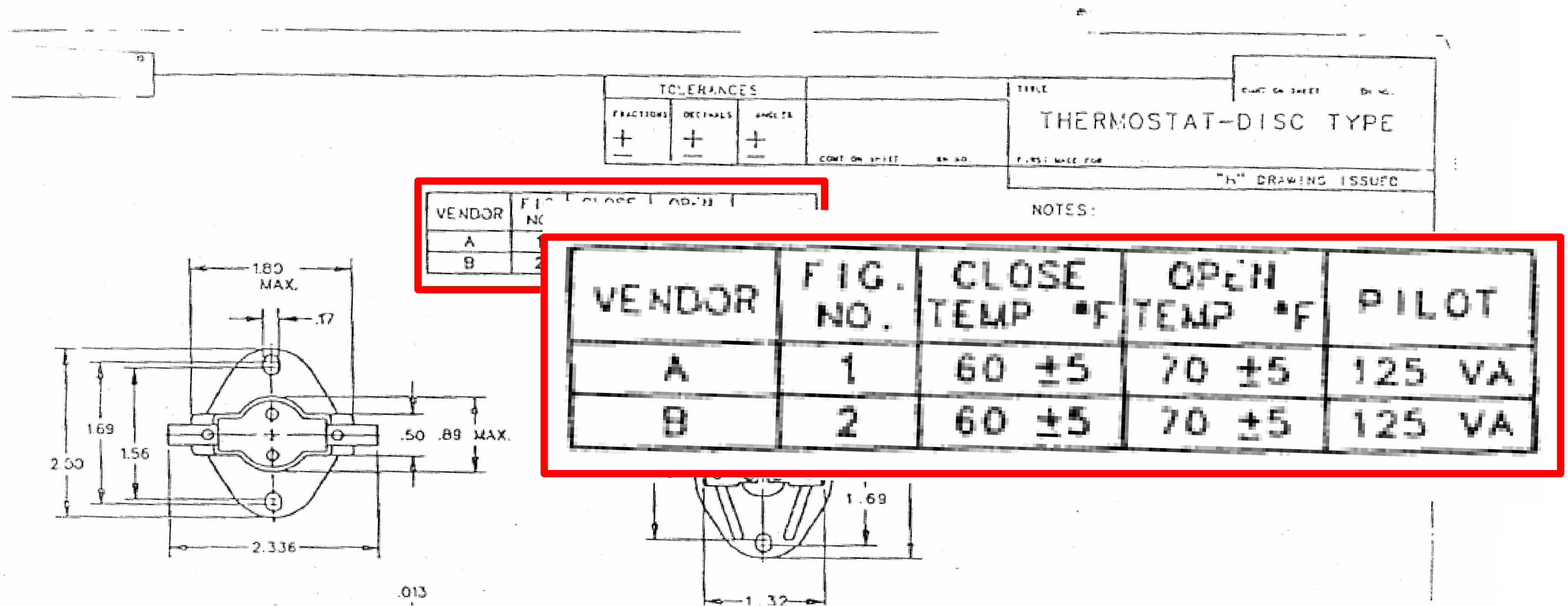
Economizer Procurement

- VRF Fan coil unit provided by 1st party
  - Includes wiring harness for economizer interface
- Economizer package provided by 2nd party
  - Includes generic wiring diagram
  - Capable of a number of change over strategies
- Economizer mixing box and controls provided by a 3rd party
  - Includes multiple product specific data sheets with a wide range of capability
- Economizer mixing box installed by a 4th party
- Economizer controls installed by a 5th party
- Economizer must interface to a building wide automation system by a 6th party to do demand controlled ventilation
- Verification of design intent by a "independent "7th party

The Result: The Economizer Doesn't Work

- Confusion regarding the pre-functional testing requirements
- Must reference:
  - Contract documents (contractor charged with developing and executing start-up and functional tests with spot checks by the Cx provider after completion)
  - Economizer package documents (generic in nature)
  - Economizer controller documents (product specific in nature but no project specific details)
  - Control system submittals (retransmits demand controlled ventilation signal and BACnet interface)
  - California energy code (very thick book)

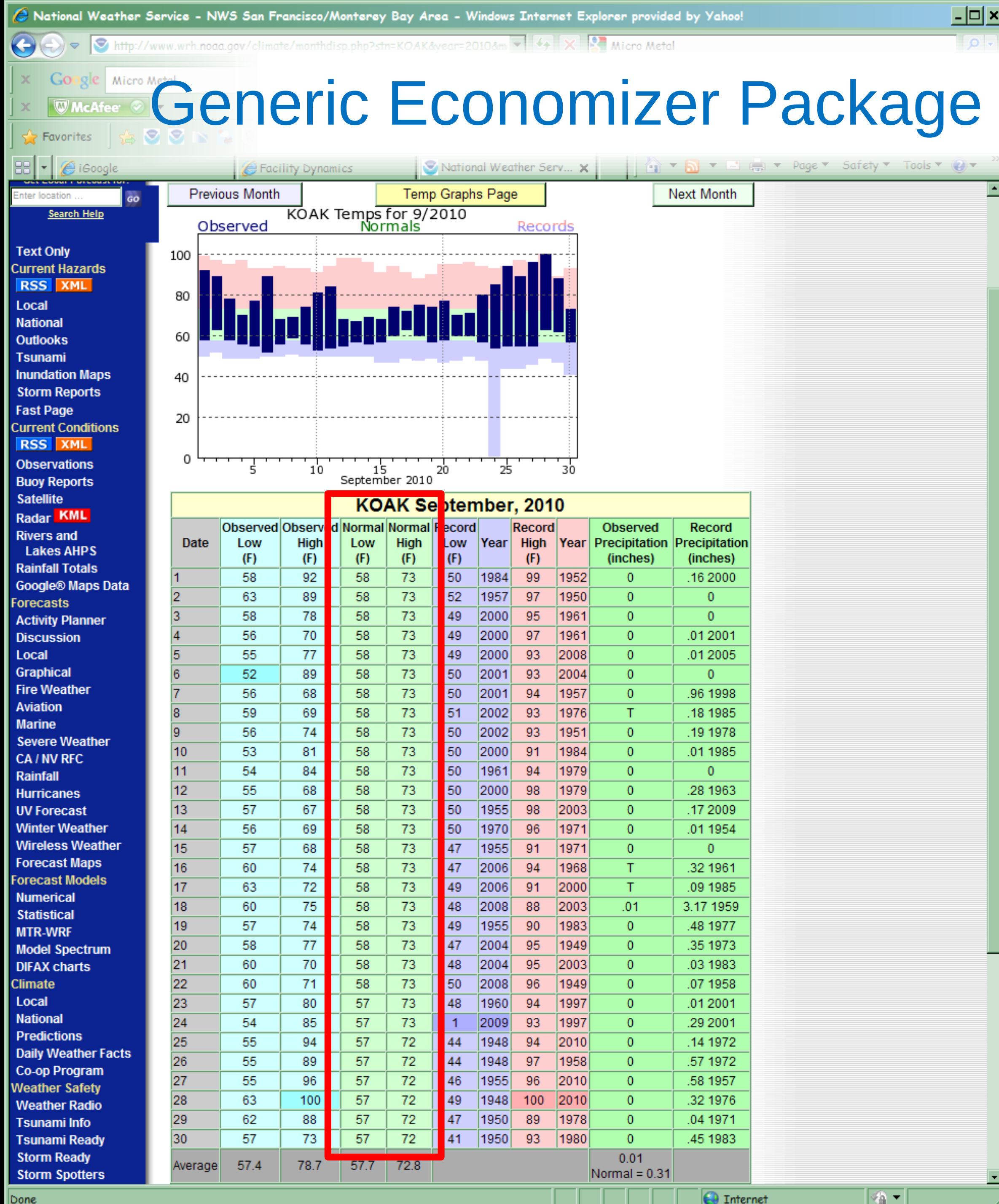
Generic Economizer Package Documents



VENDOR	FIG. NO.	CLOSE TEMP °F	OPEN TEMP °F	PILOT
A	1	60 ±5	70 ±5	125 VA
B	2	60 ±5	70 ±5	125 VA

- No wiring or check out information in one set of instructions but a lot of product specific information
- Generic wiring and a cut and paste check out procedure in a different set of instructions but no product specific information
- Both use a “clicks on” economizer change over switch as a basis of design

Generic Economizer Package Documents

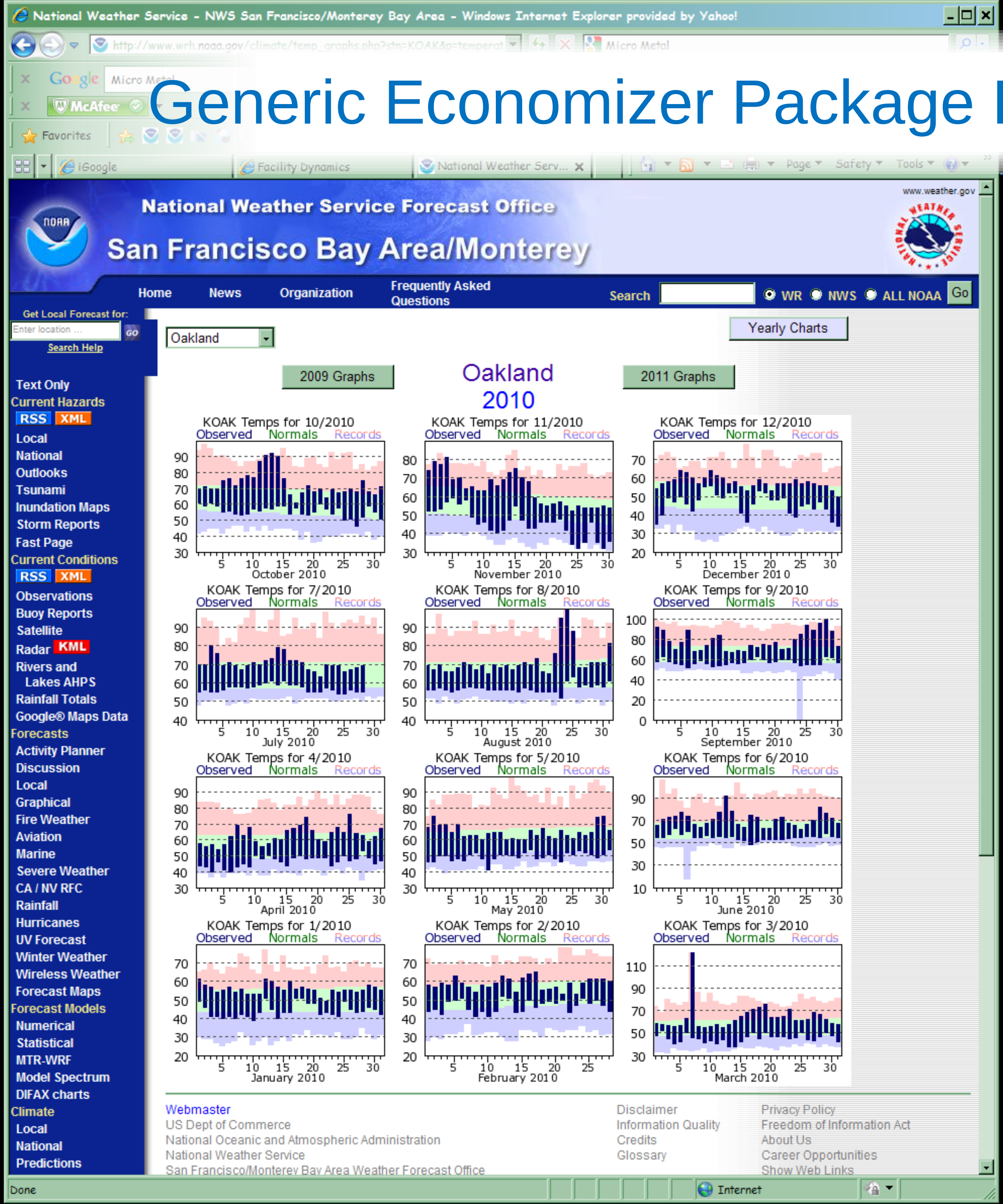


KOAK September, 2010

Date	Observed Low (F)	Observed High (F)	Normal Low (F)	Normal High (F)	Record Low (F)	Year	Record High (F)	Year	Observed Precipitation (inches)	Record Precipitation (inches)
1	58	92	58	73	50	1984	99	1952	0	.16 2000
2	63	89	58	73	52	1957	97	1950	0	0
3	58	78	58	73	49	2000	95	1961	0	0
4	56	70	58	73	49	2000	97	1961	0	.01 2001
5	55	77	58	73	49	2000	93	2008	0	.01 2005
6	52	89	58	73	50	2001	93	2004	0	0
7	56	68	58	73	50	2001	94	1957	0	.96 1998
8	59	69	58	73	51	2002	93	1976	T	.18 1985
9	56	74	58	73	50	2002	93	1951	0	.19 1978
10	53	81	58	73	50	2000	91	1984	0	.01 1985
11	54	84	58	73	50	1961	94	1979	0	0
12	55	68	58	73	50	2000	98	1979	0	.28 1963
13	57	67	58	73	50	1955	98	2003	0	.17 2009
14	56	69	58	73	50	1970	96	1971	0	.01 1954
15	57	68	58	73	47	1955	91	1971	0	0
16	60	74	58	73	47	2006	94	1968	T	.32 1961
17	63	72	58	73	49	2006	91	2000	T	.09 1985
18	60	75	58	73	48	2008	88	2003	.01	3.17 1959
19	57	74	58	73	49	1955	90	1983	0	.48 1977
20	58	77	58	73	47	2004	95	1949	0	.35 1973
21	60	70	58	73	48	2004	95	2003	0	.03 1983
22	60	71	58	73	50	2008	96	1949	0	.07 1958
23	57	80	57	73	48	1960	94	1997	0	.01 2001
24	54	85	57	73	1	2009	93	1997	0	.29 2001
25	55	94	57	72	44	1948	94	2010	0	.14 1972
26	55	89	57	72	44	1948	97	1958	0	.57 1972
27	55	96	57	72	46	1955	96	2010	0	.58 1957
28	63	100	57	72	49	1948	100	2010	0	.32 1976
29	62	88	57	72	47	1950	89	1978	0	.04 1971
30	57	73	57	72	41	1950	93	1980	0	.45 1983
Average	57.4	78.7	57.7	72.8					0.01 Normal = 0.31	

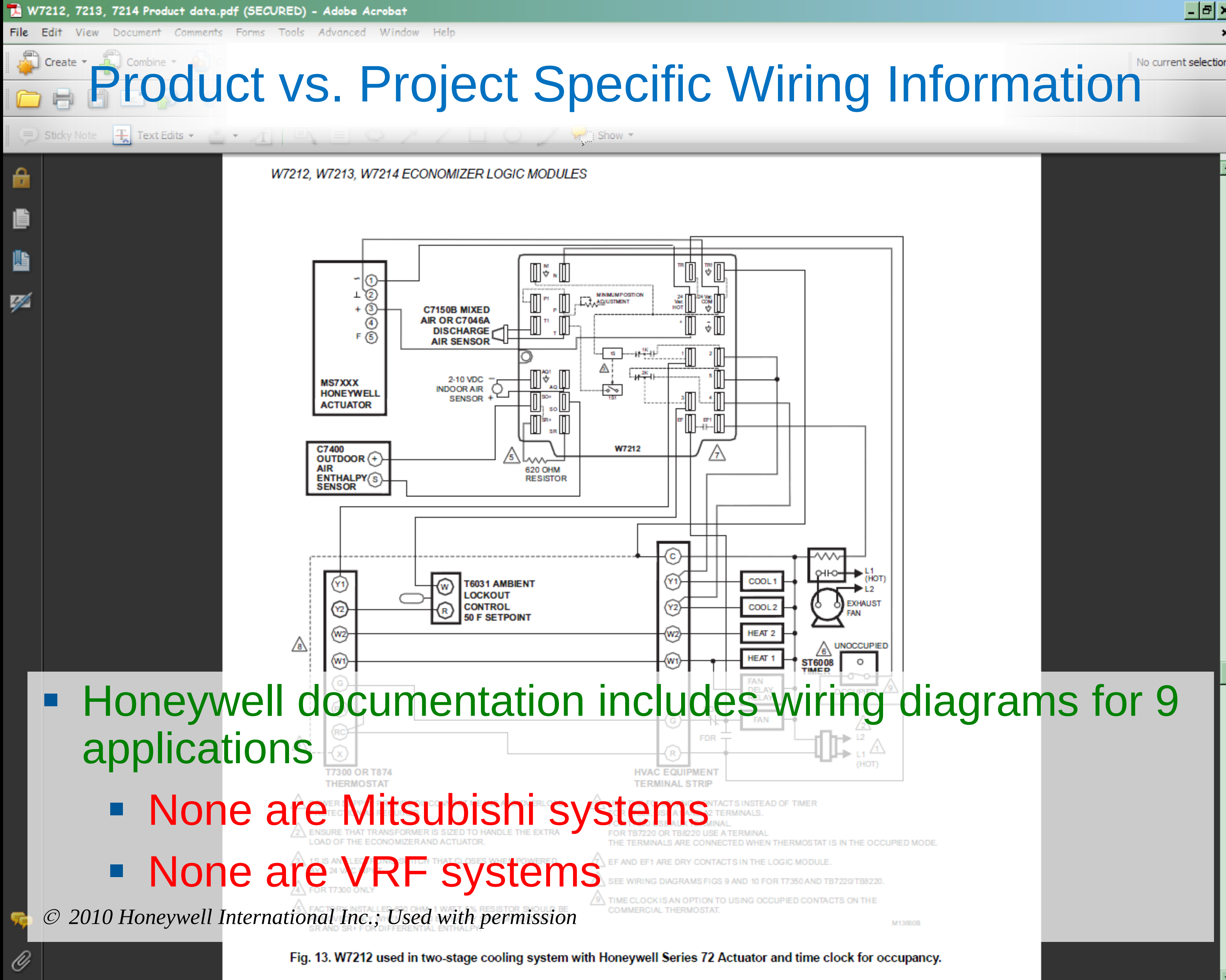
In the "normal" Berkeley climate, it would be possible for a "clicks-on" with the tolerances shown to disable the economizer in the afternoon of the first day of August and not re-enable it until September some time

Generic Economizer Package Documents



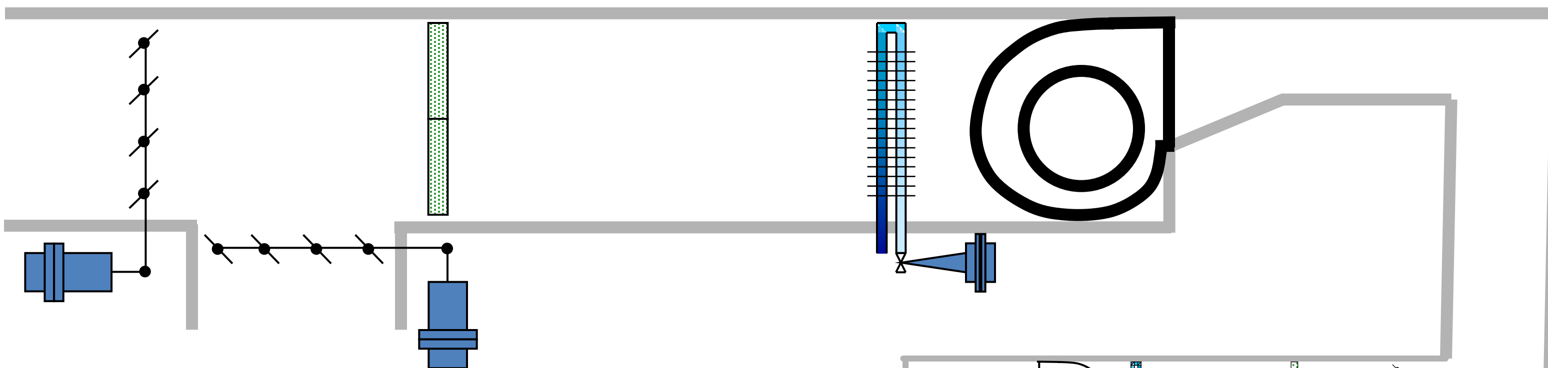
There are many days in many other months were the same thing could happen (the light green band on the graphs is the normal range)

Product vs. Project Specific Wiring Information



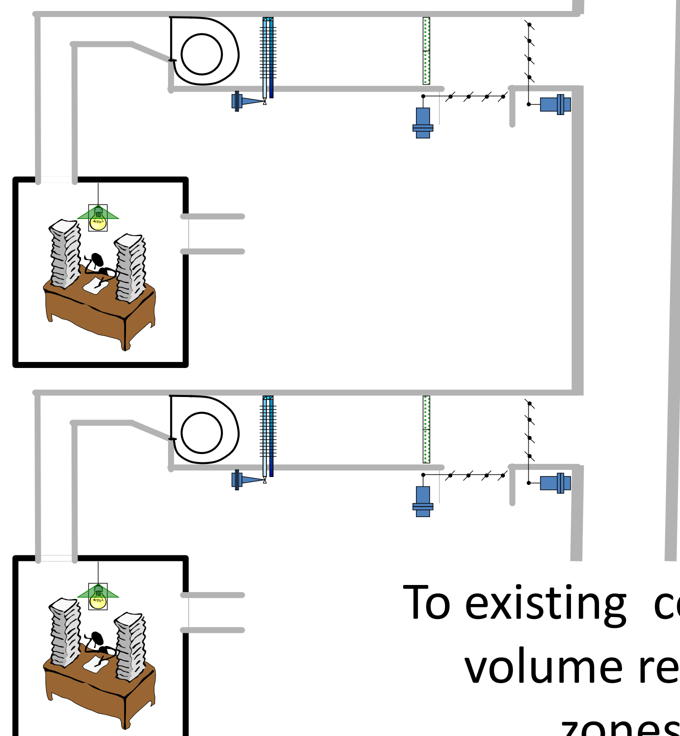
- Honeywell documentation includes wiring diagrams for 9 applications
  - None are Mitsubishi systems
  - None are VRF systems

The Actual VRF System Diagram



Outdoor air provided by an economizer equipped constant volume reheat system

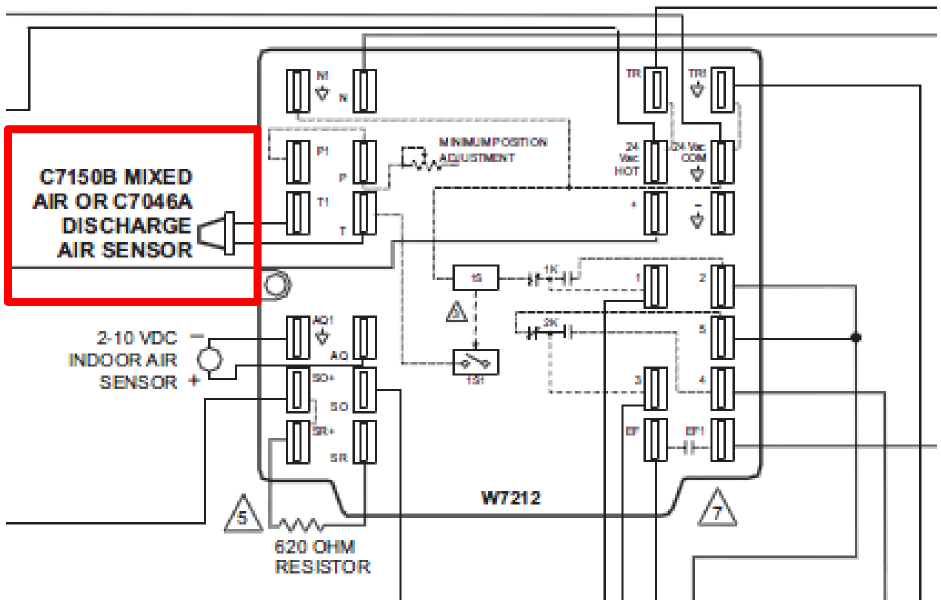
- VRF zones are variable volume and require system control strategy change
- VRF zones potentially interactive with each other and constant volume zones
- Must balance economizer benefits with reheat penalty
- VRF dampers currently not interlocked to close with VRF shut down



To existing constant volume reheat zones

Conflicting Sensor Location Information

- Discharge air vs. mixed air
- Either will work but discharge air location will cause the economizer to generally function like a non-integrated economizer
  - Bad for maximizing energy savings
  - Good for compressor replacement costs in packaged equipment with limited or no turn-down capability



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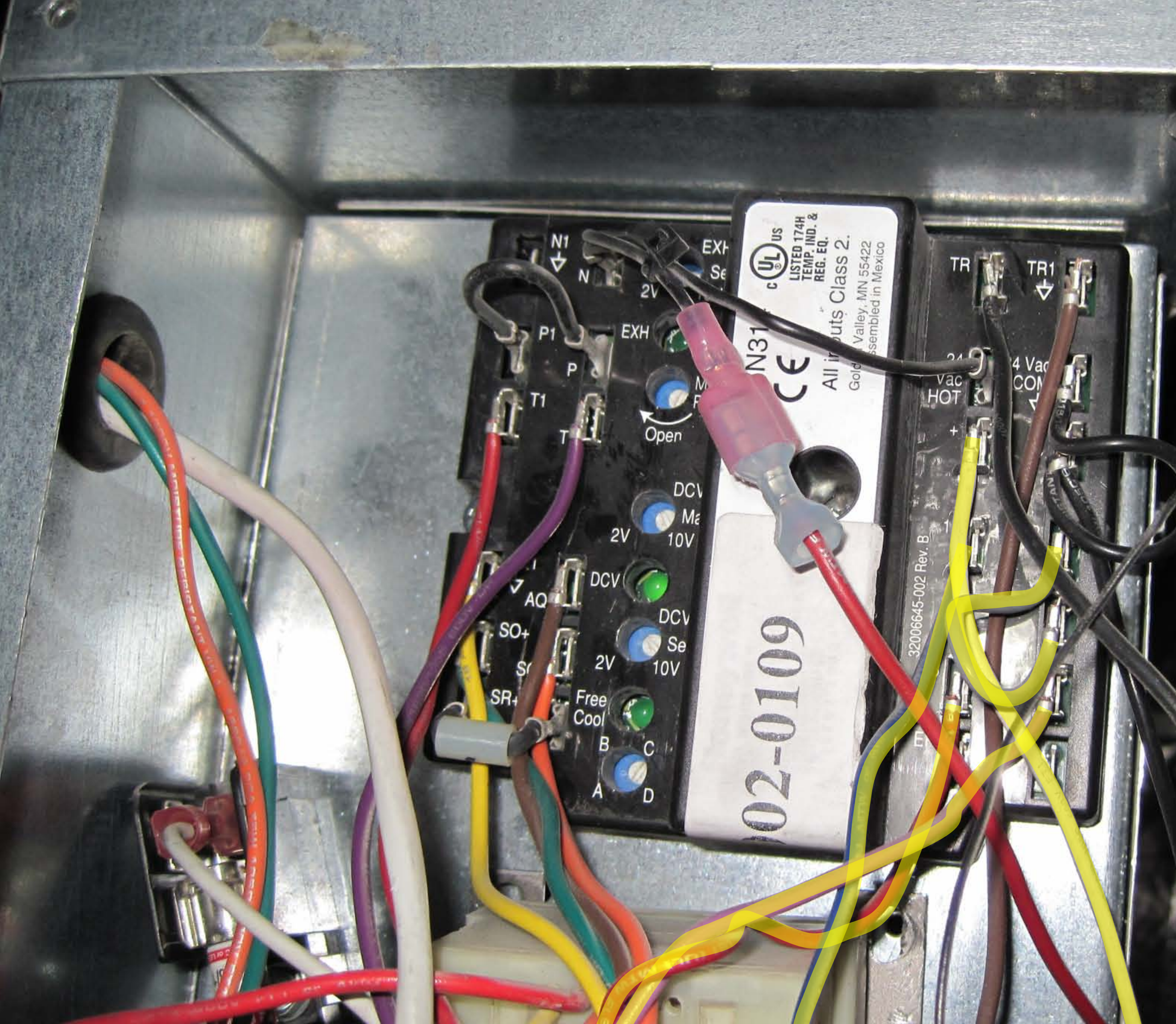
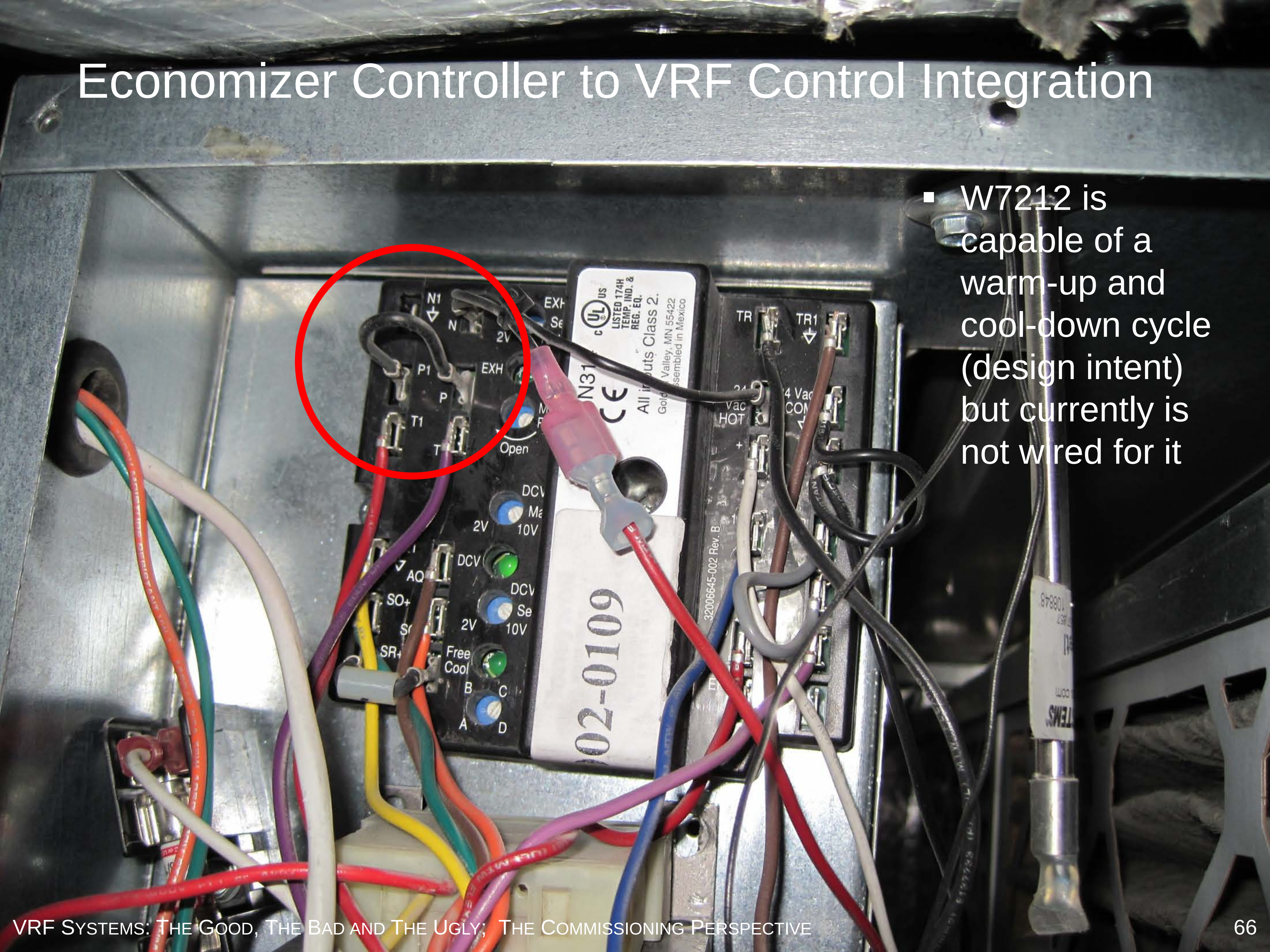
Economizer Controller to VRF Control Integration



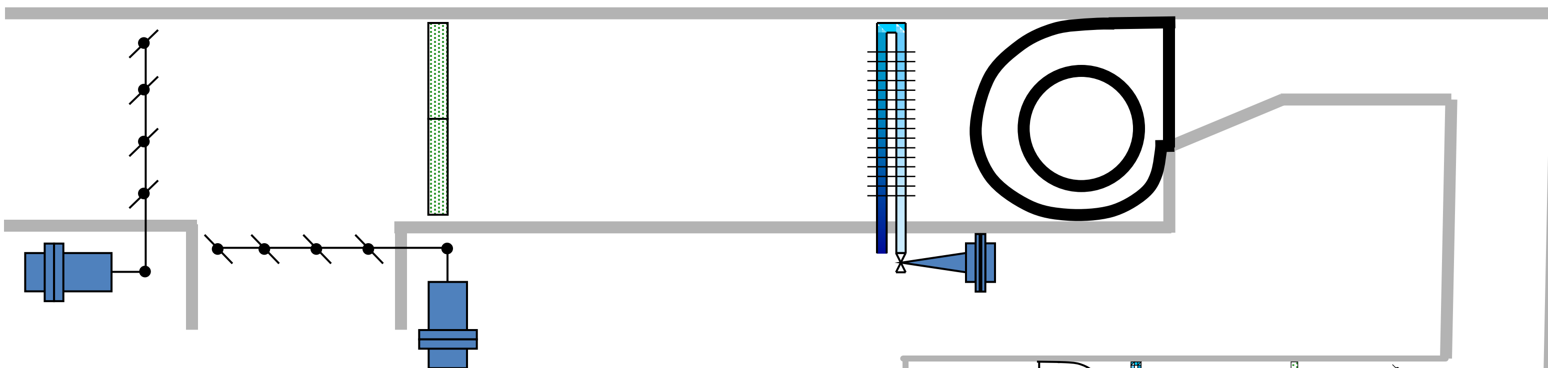
- W7212 designed to interlock with the mechanical cooling and keep it off until the economizer has a chance to work
- Economizer package wiring diagram shows no interlocks
- Field wiring for intelock is there, but where's it going?

Economizer Controller to VRF Control Integration

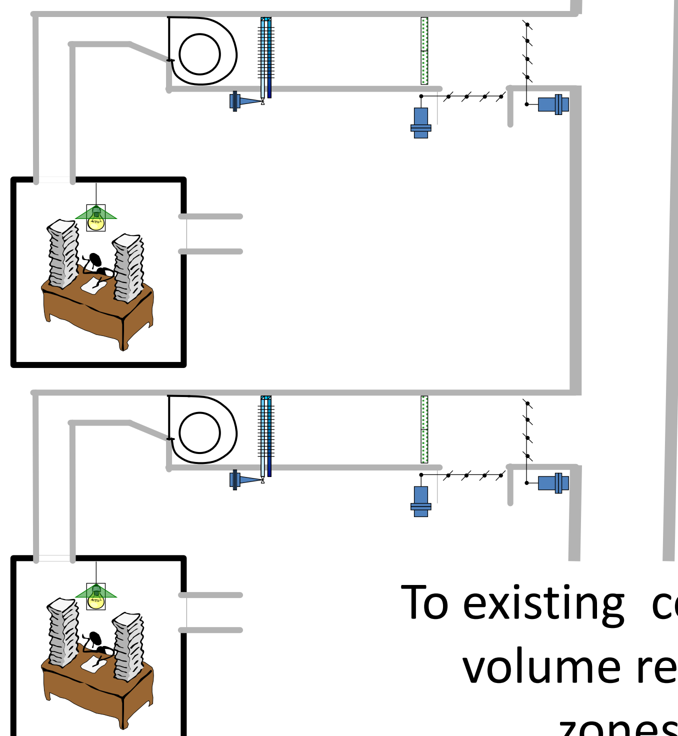


- W7212 is capable of a warm-up and cool-down cycle (design intent) but currently is not wired for it

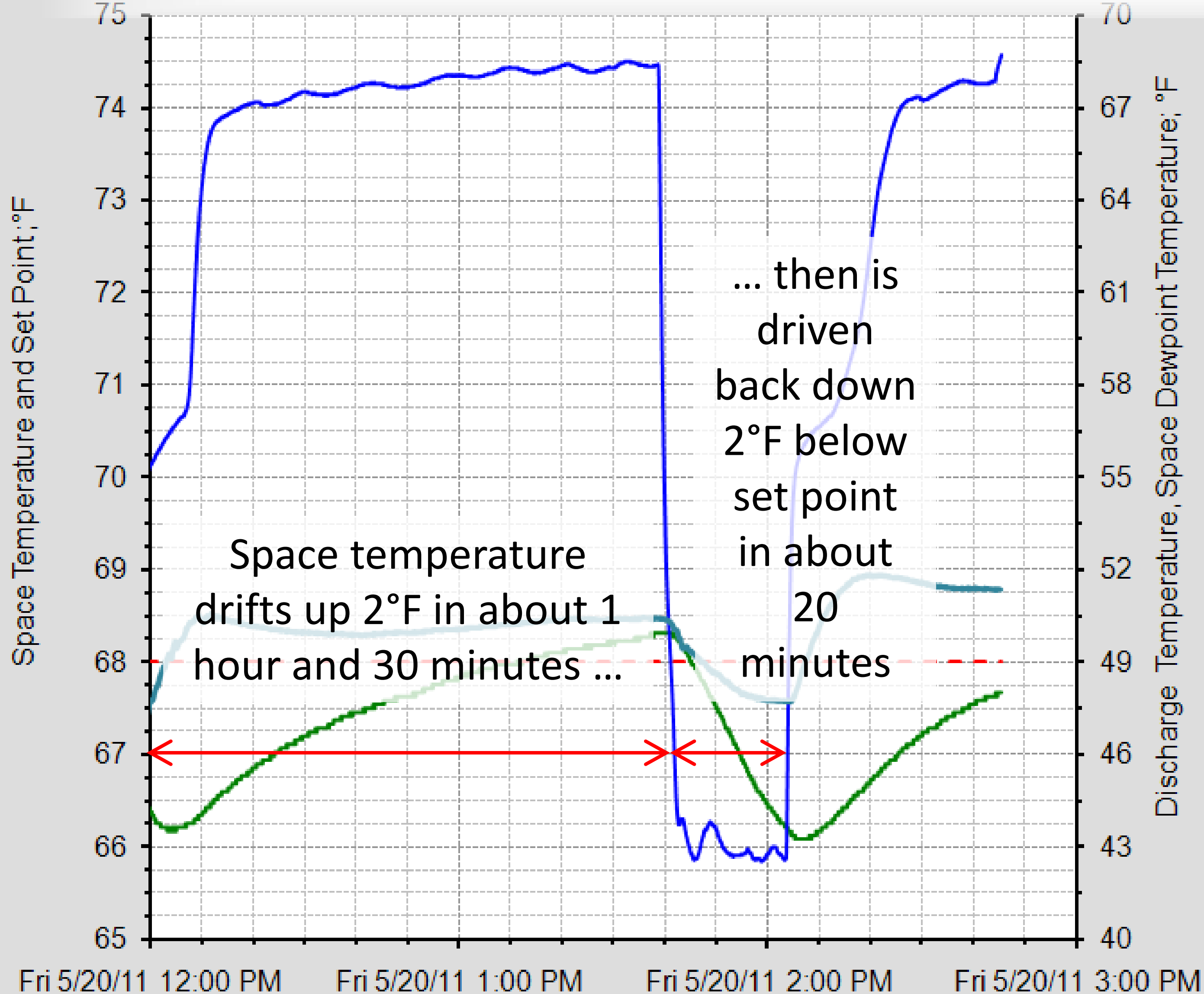
The Actual VRF System Diagram



- Main AHU schedules are provided by the building wide control system
- VRF schedules are provided by the VRF control system
- Currently no communication of schedules between the two systems

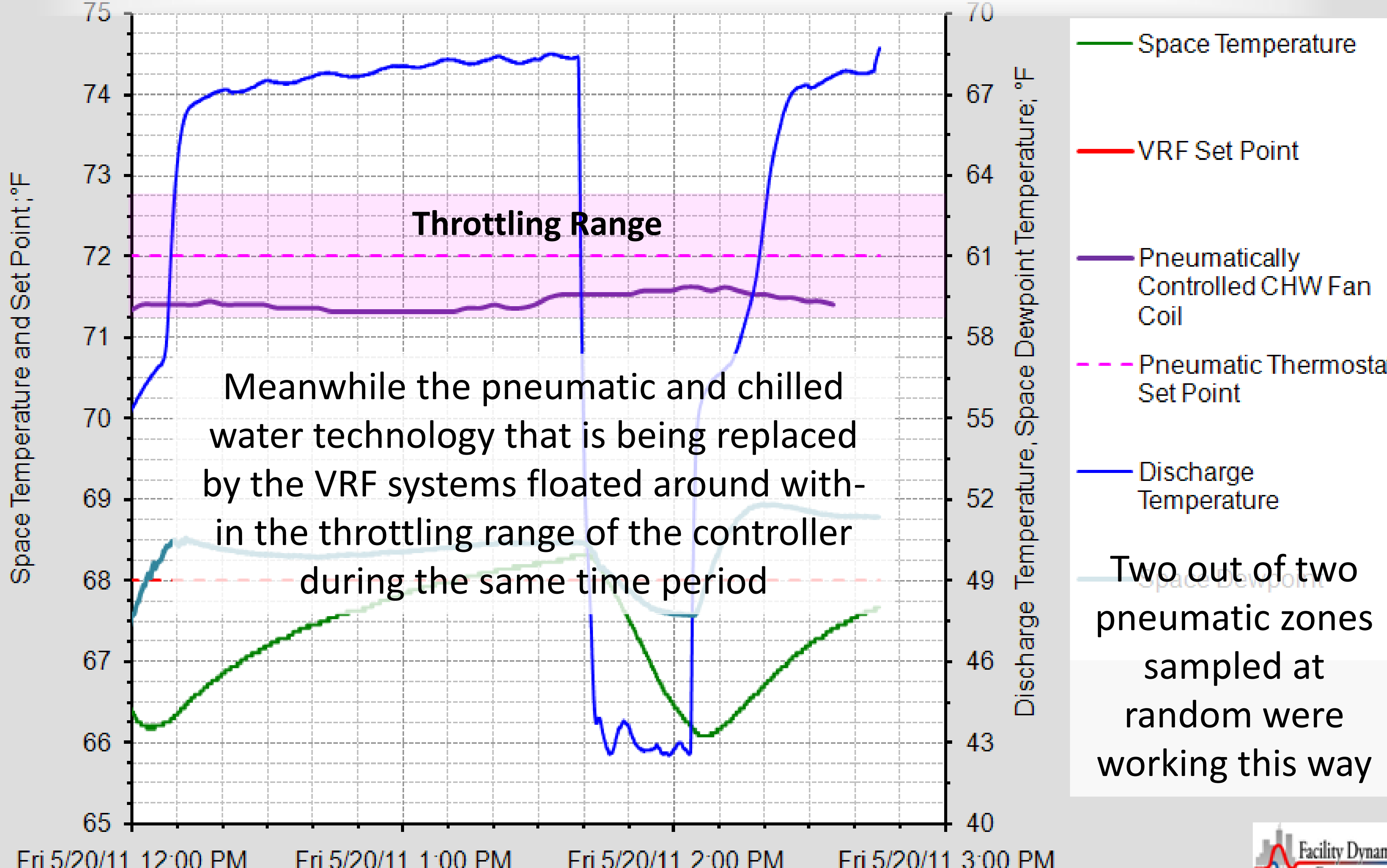


Occupant Satisfaction



Three out of four zones sampled at random so far are doing this

Occupant Satisfaction



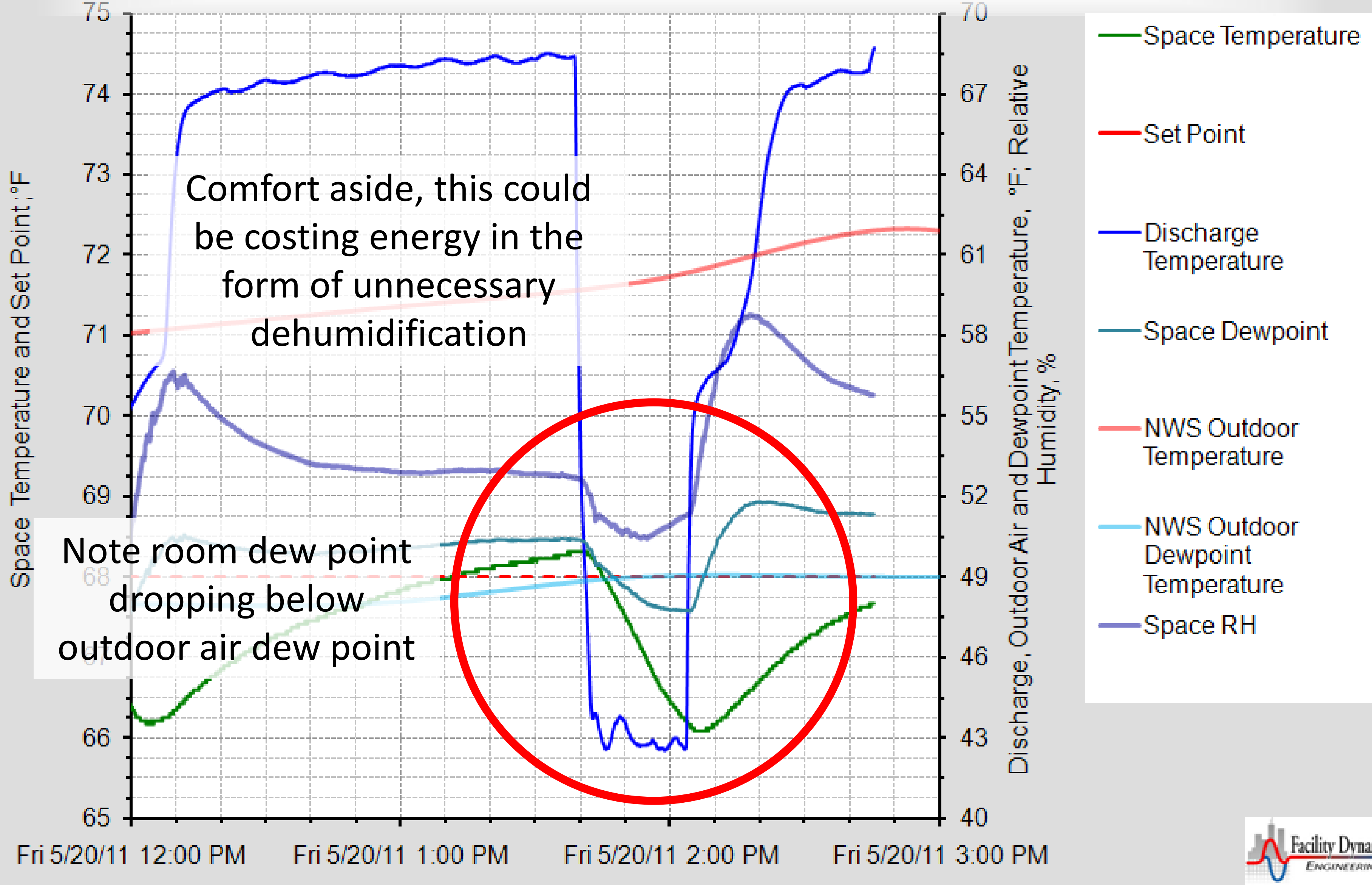
Meanwhile the pneumatic and chilled water technology that is being replaced by the VRF systems floated around within the throttling range of the controller during the same time period

Two out of two pneumatic zones sampled at random were working this way

Technology Can Have its Limitations

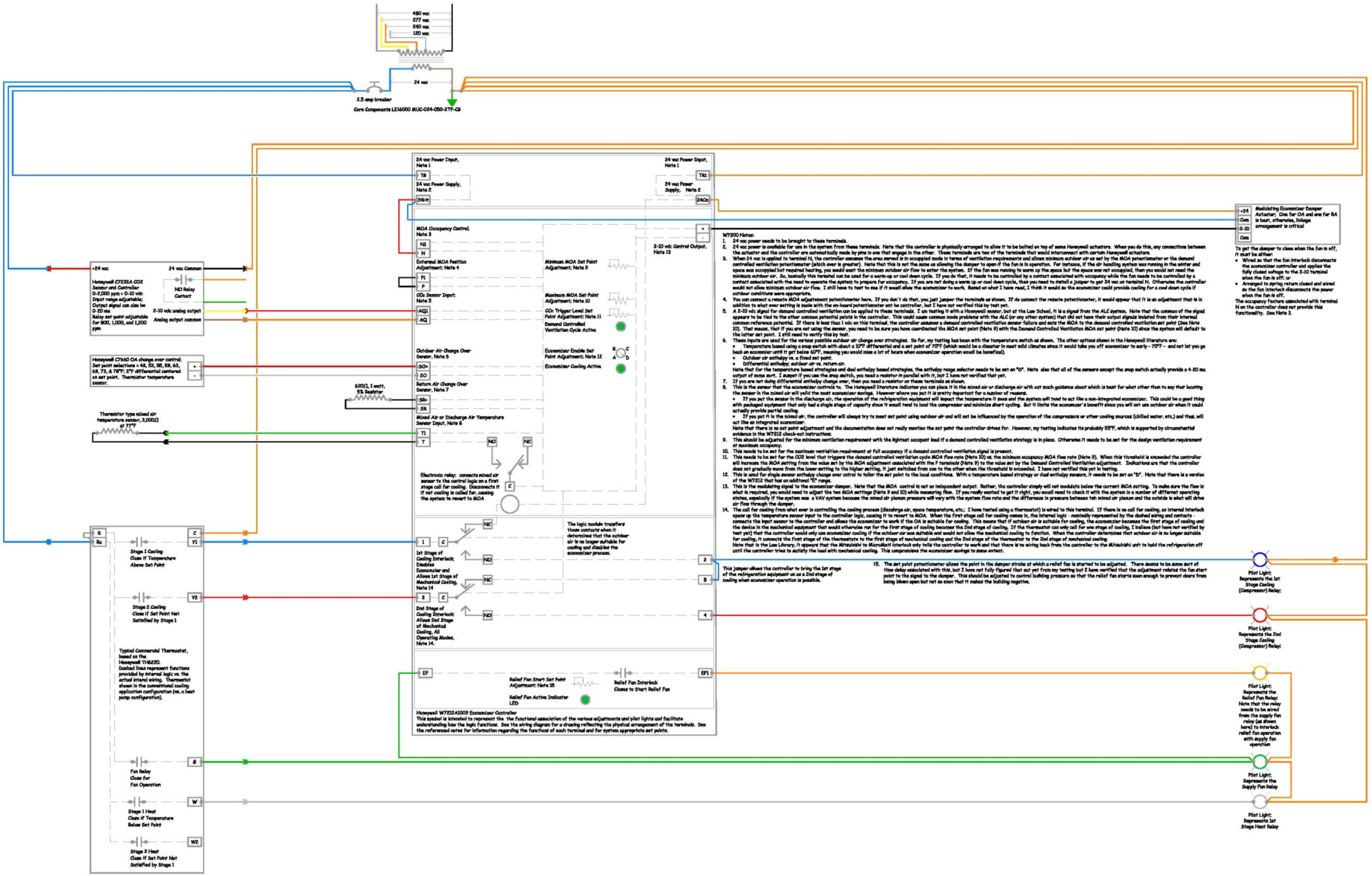
- VRF systems have turndown capability but not below about 20-25% of capacity
  - Subject to issues related to over-sizing just like any other approach
  - If the peak load potential in a zone is unknown, then you *<u>know</u>* what you *<u>don't know</u>*
    - Consider the *minimum* load potential
      - Seasonal load profile
      - Daily load profile
    - Address the current reality with provisions for the future potential
    - Make sure you understand the details of the technology you are about to embrace

Occupant Satisfaction

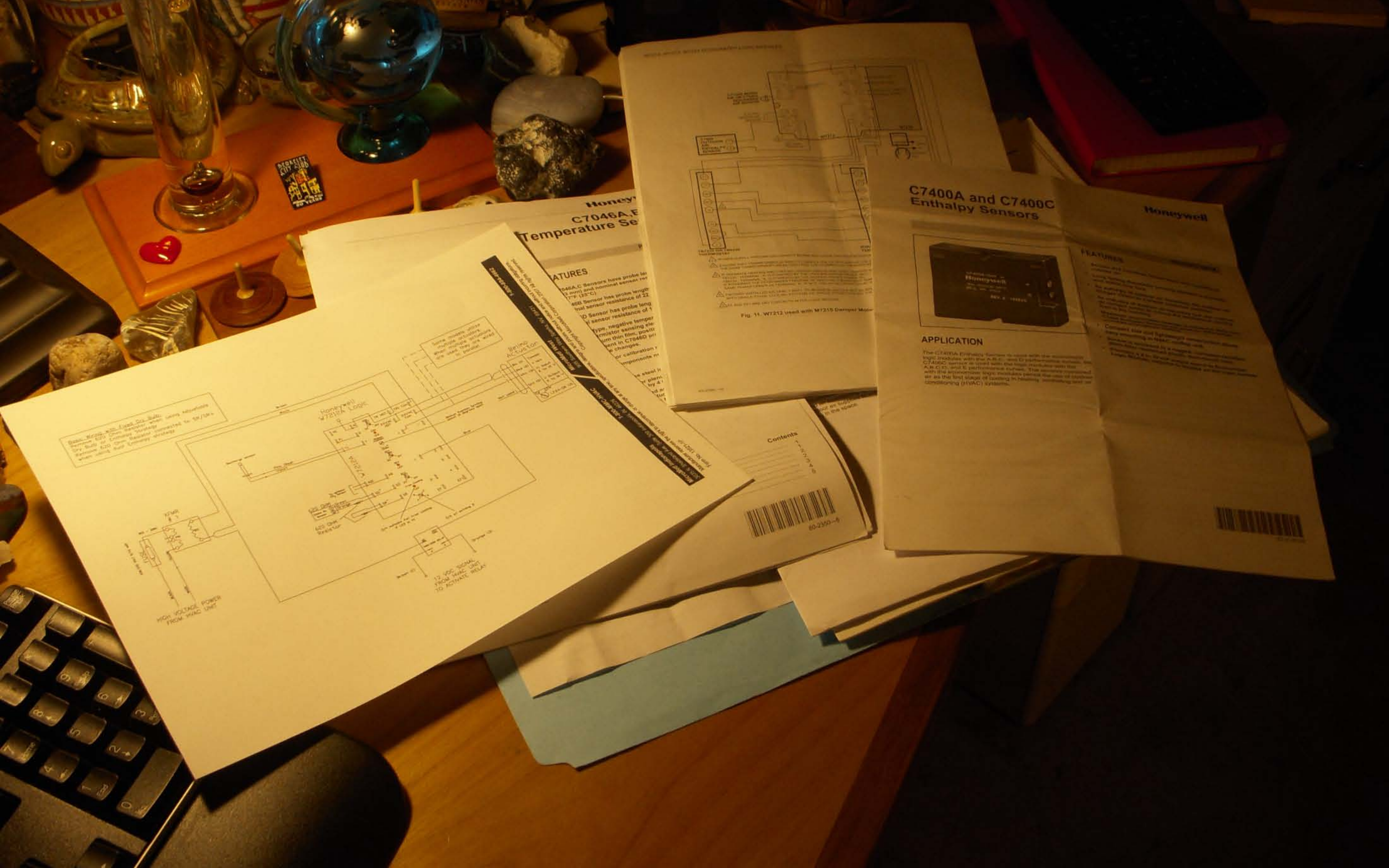


The Machinery Can Be Made to Work …

… But it Requires Attention to Detail …



… And Taking the Time to Integrate Things



Integration; The Commissioning Perspective

Early Commissioning Providers

Integrate the equipment into a working system

- Verify design intent in the short term
- Ensure its persistence in the long term

Integrate all the players into a team to identify and solve problems

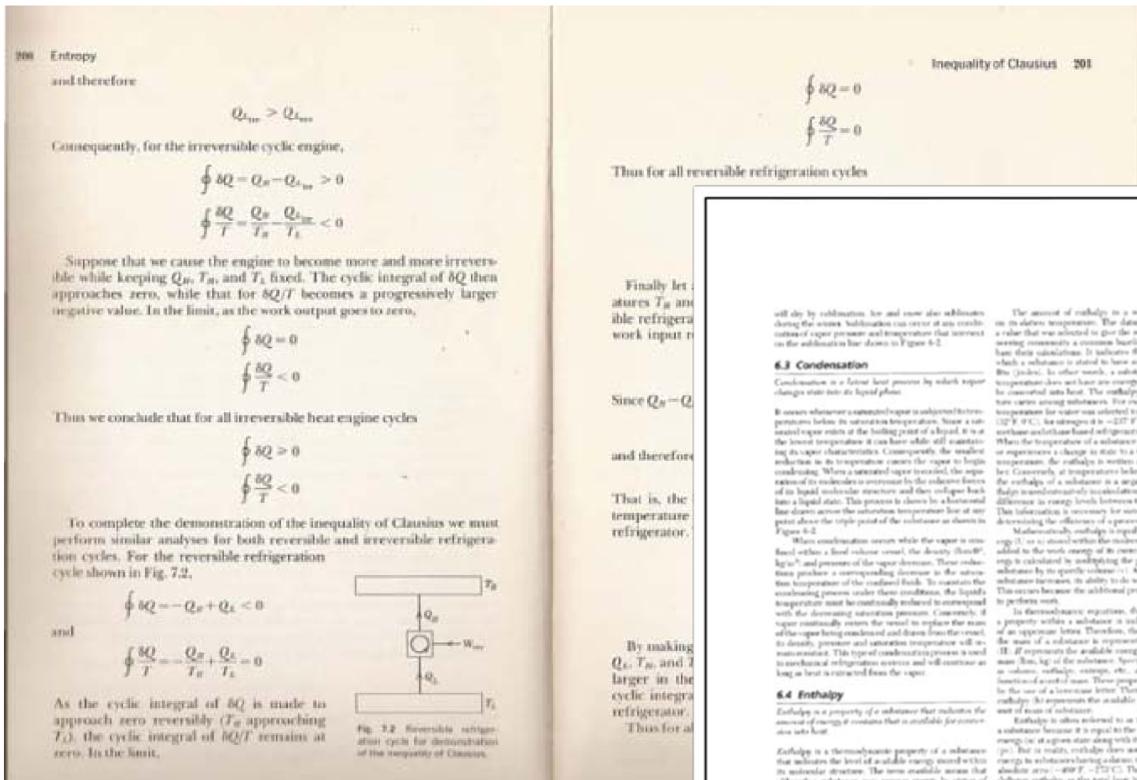
- Bring new technology into the mainstream
- Understand how it should work
- Address prototypical issues
- Ensure it things keep working for the life of the system

National Refrigerants

www.refrigerants.com

Principles of Refrigeration by Roy Dossat

Complex principles in understandable terms



200 Entropy

and therefore

$$Q_{L_{irr}} > Q_{L_{rev}}$$

Consequently, for the irreversible cyclic engine,

$$\oint \delta Q = Q_H - Q_{L_{irr}} > 0$$

$$\oint \frac{\delta Q}{T} = \frac{Q_H}{T_H} - \frac{Q_{L_{irr}}}{T_L} < 0$$

Suppose that we cause the engine to become more and more irreversible while keeping Q_H, T_H, and T_L fixed. The cyclic integral of δQ then approaches zero, while that for $\delta Q/T$ becomes a progressively larger negative value. In the limit, as the work output goes to zero,

$$\oint \delta Q = 0$$

$$\oint \frac{\delta Q}{T} < 0$$

Thus we conclude that for all irreversible heat engine cycles

$$\oint \delta Q \geq 0$$

$$\oint \frac{\delta Q}{T} < 0$$

To complete the demonstration of the inequality of Clausius we must perform similar analyses for both reversible and irreversible refrigeration cycles. For the reversible refrigeration cycle shown in Fig. 7.2,

$$\oint \delta Q = -Q_H + Q_L < 0$$

and

$$\oint \frac{\delta Q}{T} = -\frac{Q_H}{T_H} + \frac{Q_L}{T_L} = 0$$

As the cyclic integral of δQ is made to approach zero reversibly (T_H approaching T_L), the cyclic integral of $\delta Q/T$ remains at zero. In the limit,

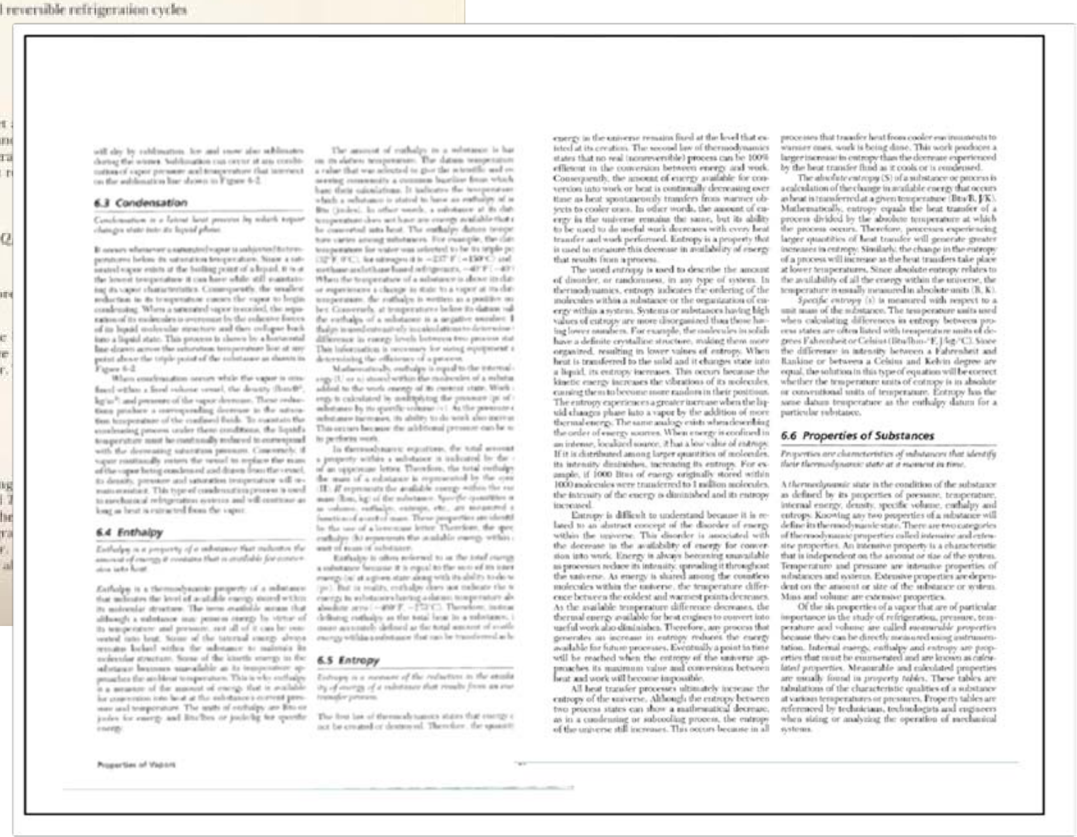
Fig. 7.2 Reversible refrigeration cycle for demonstration of the inequality of Clausius.

Inequality of Clausius 201

$$\oint \delta Q = 0$$

$$\oint \frac{\delta Q}{T} = 0$$

Thus for all reversible refrigeration cycles



6.3 Condensation

6.4 Enthalpy

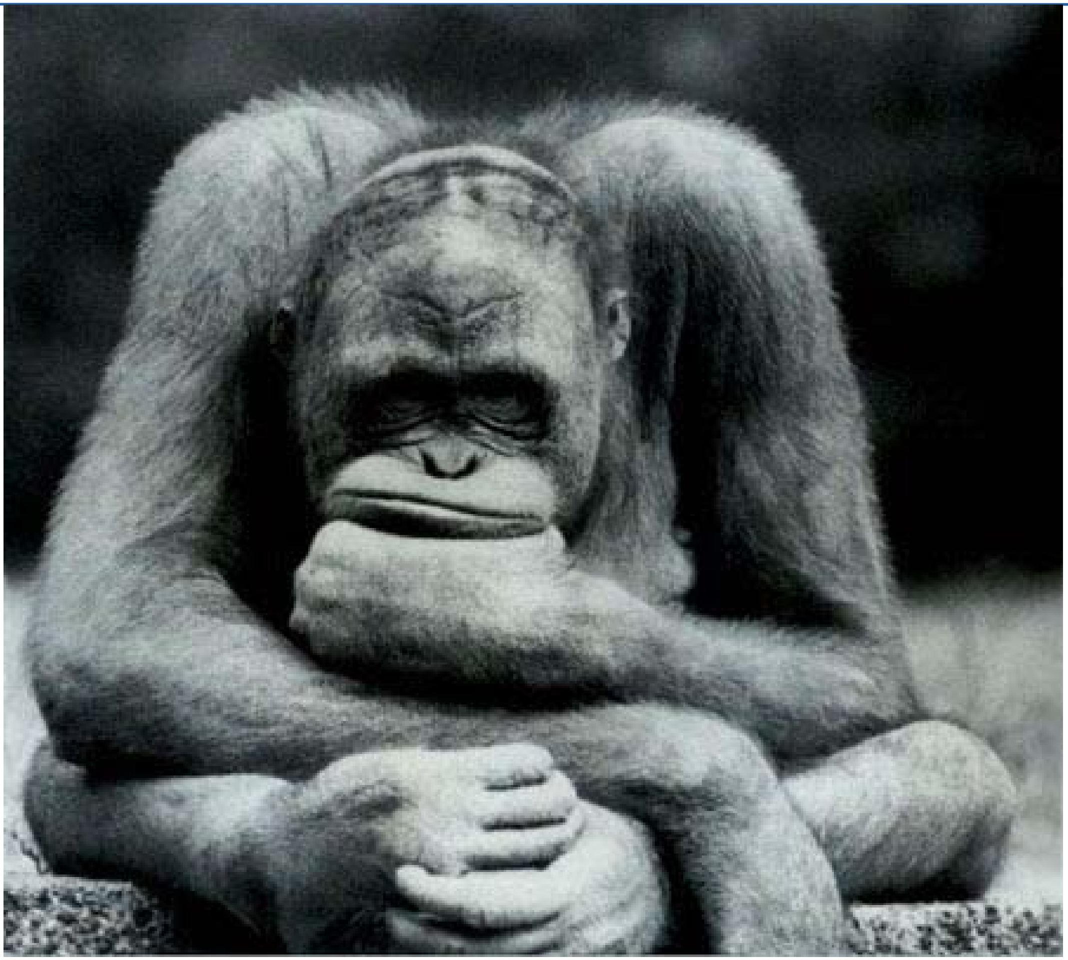
6.5 Entropy

6.6 Properties of Substances

Other Resources

- Trane Refrigeration Manual
  - http://www.trane.com/Commercial/Dna/View.aspx?i=492
- Copeland Refrigeration Manual
  - http://www.emersonclimate.com/en-us/brands/pages/copeland.aspx
  - http://lvhvac.com/cope_bulletins/aeIndex.pdf
- Sporlan Valve
  - http://www.sporlanonline.com/literature.shtml
- Mueller Brass
  - http://www.muellerindustries.com/
- ASHRAE Journal
  - *Variable Refrigerant Flow Systems* by William Goetzler, April 2007; www.ashrae.org

Questions



Appendix 2 – Flare Joints

Memorandum

Date: September 16, 2010

To: Jim Wert; UCB Capital Projects

From: David Sellers; Facility Dynamics Engineering

Cc: Alan Daly; Taylor Engineering

David Sasai; UCB Capital Projects

Gary Kawabuchi, Ron Simens; Facility Dynamics Engineering

Re: UCB Law Building Infill Project – Leaking Flare Fittings

If you are reading this memo in the electronic version, the table of contents below can be used to move around quickly in the content. Click on the topic of interest in the contents list below and you will be linked to that location in the document. Use the back arrows on the Web tool bar to get back to where you came from (the web tool bar should open up the first time you use a link; it's the one with the little world with a magnifying glass icon in Office 2003 and with two green circles with arrows in Office 2007). You can also click on references to figures and tables to jump to them in a similar manner.

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- Joint Fabrication 4
- Tightening the Connection 5
- Vibration and Stress at the Point of Connection 6
- Conclusions 6

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Summary

This memo presents the results of informal research and analysis on my part, targeted at understanding the characteristics of a proper flare connection in the general case and in the specific case of the Mitsubishi equipment. As we have discussed, there have been issues on this project with leaks at flare fittings. My understanding is that this has also been a concern on other projects on campus that have Variable Refrigerant Flow (VRF) systems but I don't have formal documentation of that; only hearsay.

The conclusions I reached are as follows.

- The use of flare fittings in refrigeration systems is common and is in fact one of the intended applications for the fitting design as indicated by the name of the applicable SAE standard (*SAE J513d – Refrigeration Tube Fittings*) which was originally developed in 1936. Thus, it is more likely that any problems we are having are related to application issues and the way the field flares are fabricated than they are related to the fittings or misapplication of the fittings themselves, barring some sort of manufacturing defect.
- Flare connections are used because they provide reliable leak free connections that can be assembled without flame and disassembled when necessary.
- The sealing mechanism is intended to be metal to metal surface contact with lubricant applied to facilitate making up the joint. But a reliable, leak-free connection should result without the application of additional sealant. In fact the presence of some sort of sealant on the face of the flare could make the joint less reliable and more prone to leak.
- Details of how the field flare is fabricated and secured, including the hardness or softness of the tubing that is flared, the type of tool used, the face dimension and diameter of the flare, the way the joint is supported, and the way the joint is tightened can all come into play in terms of the success or failure of the joint. Thus, attention to these seemingly minor issues may be the difference between success and failure in terms of the viability of the connection.
- There are critical differences between specific details of how a flare connection is made and the pressures it has to deal with in an R410 system (a relatively new refrigerant to the field, especially in smaller equipment but the refrigerant used in the Law Building systems) and an R22 system (one of the most common refrigerants in use in the recent past). Thus a field technician who was not familiar with these differences could in advertently create bad flare connections in an R410 system using techniques that had served them well for years on an R22 system.
- Based on a review of internet discussion boards, there is a significant difference of opinion in the field technician community with regard to the specifics of making a flare connection both in the general case and in the case of R410 systems.

- The Mitsubishi engineering, installation, and technical service manuals have the following consistent themes with regard to flare fittings.
  - Cleanliness is essential through-out the process.
  - Tools used with R410 systems should only be used with R410 systems.
  - Lubrication with oil that is compatible with R410 is essential when making up the joint.
  - Two wrenches should be used when tightening the joint.
  - The piping and equipment need to be adequately supported to prevent loads from being applied to the flare connections.
- There are details related to the manner in which the flare joints are fabricated and assembled that have implications beyond the integrity of the flare joint, including the potential to cause operation problems, motor failures and compressor failures if they are not properly addressed.
- The Mitsubishi requirements are consistent with the requirements found in the general case for flare fittings. Thus, there is no reason to believe that they would not provide a reliable, leak free joint. And, there is no reason to not adhere to them and ask/verify that they are complied with as the standard for installation is a reasonable and desirable first step in ensuring the long term integrity of the re FRF systems.
- Developing some sort of mechanism for logging the specifics of joint failures on the project may be a useful tool to diagnose the root cause.

The remainder of this report presents the information and analysis that lead to the conclusions outlined in this section.

Introduction

After realizing that we seem to be experiencing a number of leaks in the systems after they have been in operation and that the leaks seem to be at flare connections, I started to wonder if the problems were related to some detail of how the connections were being made up. As you will recall, we looked up the requirements for connecting a line set to an indoor unit in one of the Mitsubishi instruction manuals for the project while at lunch last week and found some fairly specific requirements.

Subsequently, I spent additional time reviewing the installation manuals and found similar information in all of them. I have included copies of some of the installation and technical service manuals representative of the equipment on our project for reference as an appendix for reference. Generally, they reflect the requirements I found in all of the manuals I looked at.

I have also spent some time researching flare connections in a number of resources including past editions of the Society of Automotive Engineers (SAE) handbooks, , ASHRAE Handbooks, Piping Handbooks, the internet, and even regulations, references and recommended practices from my aviation days. The bottom line is that while there are some differences between sources, and certainly some differing personal opinion among refrigeration mechanics on discussion boards, technically there seem to be some common threads that also seem to appear in the Mitsubishi requirements. The remainder of this memo will discuss what I believe to be the pertinent technical issues in the general case and then in the specific case of our project.

General Case

In general terms, flare connections are cited for their long term reliability while still allowing the joint to be disassembled and reassembled without the need for heat or special tools once it is fabricated. To the best of my knowledge, the standards behind flare fitting have their origins in a series of SAE standards with *SAE J513d – Refrigeration Tube Fittings* appearing to be the applicable standard in our instance for the fittings and *SAE 533b – Flares for Tubing* being the general standard governing the details of the actual tube flare for use with both 45° and 37° fittings. I have included copies of versions of these standards in *Appendix 1*.

These standards have been in place for a while; since 1936 for the fitting standard and since 1947 for the tubing standard. I think this is important for a number of reasons.

- I t would tend to indicate that the details of the approach have been in place and applied for a significant number of years and are well beyond any development problems that may be associated with a new technology.
- At the time they were developed, engineering was a much more "hands-on" profession than it generally is today. That is to say that the people that developed the hardware then got dirty and actually worked with the hardware to "start her up and see why she doesn't work"[1].
- The approach alluded to in the preceding bullet tended to lead to hardware that worked in the real world, not just in theory.

Fittings based on these standards are applied in many industries with demanding and critical applications, including aerospace, where the implications of a failure are perhaps the most serious.

Sealing Mechanism

Most sources I found cited the sealing mechanism as being metal to metal contact between the flare fitting and the fabricated flare on the tubing. In other words, no special sealants should be required to achieve a satisfactory, leak free joint.

That said, at least one manufacturer (Eaton) markets a special gasket designed to seal between the face of the tube and fitting for hydraulic system flare connections (37° flares; most refrigeration flares, including the ones in the Mitsubishi equipment are specified as 45° flares).

Joint Fabrication

The metal to metal method of achieving a seal makes the tolerances and integrity of the fitting and fabricated flare critical. There are at least two different flare angles in common use; 45° and 37°. I found one reference to 60°, but not in a technical resource.

My point is mentioning this is that it opens the door to the possibility of fabricating the flare with the wrong angle for the fitting you are working with. While unlikely, it's not impossible and one of the

[1] John Fritz as quoted in *The Pratt and Whitney Aircraft Story*; he was known for saying this after completing work on a new machine he had designed.

places I saw reference to the different flare angles was on a discussion board, where refrigeration mechanics were discussing the reliability of the joint.

I know from personal experience in my airplane mechanic days that it is not impossible to fabricate the wrong size flare on a tube and make up the connection. As I recall, they intentionally had us do it so we would realize that there were at least two different standards. It doesn't feel right when you do it once you know what the joint should feel like when you make it up. And the mismatch leads to leaks. But it is possible to use the wrong tool and flare angle for the fitting you are working with and have it go together, sort of.

Cleanliness is also critical, both when fabricating the joint and when making it up. If debris gets under the flaring die, it can scar the sealing surface. If debris gets in the connection as it is being made up, it can prevent full metal to metal contact from being achieved.

From what I can tell, for best results, you need to anneal the copper so it is soft before you make the flare. That means if you are running hard copper tubing and needed to make a field flare and did not anneal the end of the tubing first, you could have a less than optimal result; there could even be cracks in the flare.

There also seems to be general agreement that the tube needs to be cut squarely, be free of burs, and that the dimension that the tubing protrudes through the flaring tool is critical. The latter will impact the amount of surface area that exists for metal to metal contact between the flare and the fitting, which would seem to have something to do with the sealing capability. I found at least one reference to using a gauge to correctly set the extension of the pipe beyond the flaring tool.

Tightening the Connection

Most sources I found cited the need to apply some form of lubricant (not sealant) to both the face of the flare and the fitting and flare nut. Generally, the reason for this is that it minimizes the tendency to twist and distort the flare as the fitting is tightened and also helps ensure a uniform distribution of the compression force across the face of the flare. This makes logical sense when you consider what happens when you tighten a two piece flare fitting. There are other flare fitting designs that get around this by using a sleeve between the tubing and nut, but I don't recall seeing them in refrigeration systems. I have encountered them in hydraulic systems.

Most sources also emphasized the need for the lubricant used on the joint to be compatible with the fluid circulated in the system. Failure to do so could result in contamination of the system and equipment failures. In some instances, the recommendation was to ***not*** use lubricant for this reason.

Many of the sources also reference using the correct torque for the connection, implying that you should use a torque wrench of some kind. The consensus on the penalty for over-torque seemed to be the potential to deform, thin, or even work harden the flare, all of which could lead to failure. The consensus with regard to under –torque was the potential to not achieve adequate metal to metal contact, which is the sealing mechanism. These conclusions both make logical sense when contemplated from a fundamental standpoint.

Many sources also cited the need to use two wrenches when making up the connection, one on the nut and one on the fitting to minimize stress on the joint while it was being tightened.

Vibration and Stress at the Point of Connection

As an aircraft mechanic, one of the rules I learned about fabricating hydraulic lines was that you should never install a hydraulic line as a straight connection between two points. Rather, there should be a bend in the line to absorb any stress that might be set up by the relative motion between the two locations. The relative motion could be the result of relative movement of different parts of the air frame, vibration, and differential expansion caused by temperature changes to name a few things.

I found one discussion on line about the potential for a flare joint to fail over time at the radius of the flare if there was vibration in the line. The concept seemed to be that if there was relative motion between the pipe and the structure and equipment that it was connected to, the vibration would tend to work harden the copper and lead to a failure at the weakest point or stress concentration, which could easily be the radius of the flare. Practical experience with breaking wire and thin metal by bending back and forth at the same point a number of times tends to make me think this could occur.

Conclusions

While my research was far from extensive, my conclusion after performing it is that there are a lot of details that need to be address if you are going to make a leak free flare joint. And, there seems to be some confusion about the specifics of the details including the proper flare angle (at least two standards exist), the tube dimension protruding beyond the flaring tool when fabricating the flare, the need to lubricate, and the specific torque requirements.

Thus it would seem possible that a mechanic or technician with the best of intentions could make a poor flare joint, either because of their exposure to the multiple opinions and having to make a decision or because they are not aware of the fact that the specific requirements of a certain procedure can vary from system type to system type. For example, there are very strong opinions on the web forums about if you should or should not lubricate a flare when assembling it. And if you do lubricate the flare (which I believe is the technically correct thing to do) the oil that you would use to lubricate a fitting for an R-22 system would not be the right oil to use to lubricate a fitting for an R410 system.

Compounding the potential for problems, I think, is the fact that the refrigerant used in the Mitsubishi VRF units is R410. This means that the pressures we are working with are higher than what we would consider normal from working with other refrigerants like R-22. For instance with an R410 system the low side runs over 100 psi and the high side can approach 400 psi in normal operation. In contrast, in an R22 system would tend to run in the 60 psig range or less on the low side and at or below 250 psig on the high side. As a result, for a given line size the stress and other factors that would tend to cause a refrigerant leak, especially at mechanical connections, will tend to be higher for these systems than with the refrigeration systems we have worked with in the past. I think this means that the potential for a leak if the details of the joint are not correct is much higher.

All of that said, a flare connection, properly made, should be able to provide a reliable, leak free connection in the systems we are dealing with in the library. Thus, any failures we are experiencing are most likely related to the method of fabrication and assembly or other field conditions.

Project Specific Case

After spending some time trying to understand the technical details behind flare connections in general, I spent some time with various engineering, installation, operation, and technical service manuals for the outdoor units, indoor units, and branch controllers on our project. All of the applicable manuals that I can find are also loaded on the CACEA portal.

For the purposes of the discussion in this memo, I have included an example of manuals for each device (indoor unit, branch controller, and outdoor unit) for reference as an appendix. I selected these manuals because the all reference the installation of the refrigerant piping and related flare connections. The technical service manual for the outdoor unit is the most detailed. If you look at the other manuals, you will find that they generally reflect the technical service manual requirements, sometimes with less detail and in some cases reference the outdoor unit manuals as resources to be consulted for additional details on requirements and documentation.

Sealing Mechanism

There is nothing to suggest that anything but metal to metal contact as the sealing mechanism for the flare joints in the Mitsubishi systems. There are no references to joint compound, gaskets, or any other auxiliary means of achieving a seal.

Joint Fabrication

Several of the manuals include a detail of the flare connection that shows it to be a 45° flare. Figure 6.1 on page 3 of the *Mitsubishi Indoor Unit Installation Manual* in *Appendix 1* is an example of an illustration found in many of the manuals detailing this.

Additional discussion of the details of the flare fabrication can be found in Mitsubishi Outdoor Unit Technical Service Manual in Appendix 2. This reference specifically points out that the flare outside dimension to be used with the R410 equipment is different/larger than the flare that would be used with R22 machines. The difference is modest (about a 1-3% difference in diameter of the formed flare which would be compounded in terms of surface area – i.e. sealing area by the related circumference), but appears to be important enough to be highlighted in the technical information associated with the equipment.

Figure 1 – Mitsubishi Line Set: A line set like this would still require a field flare to make the connection to the fitting on the left assuming the flare nut on the right was used to make the connection to the branch controller.

Since this is a minor dimensional difference that does not seem to be called out in all of the manuals, it is not out of the question that a technician faced with making a field flare would not be aware of it and as a result, the flare would not have the seating surface available anticipated by the factory engineering.

This is probably less of an issue if factory line sets are used since the flare would have been formed in the factory (see Figure 1). But, given what appears to come with a factory line set, it would seem like there will still be a field flare required to interface with the factory line set.

Cleanliness and keeping the piping and connections free of moisture is emphasized in most of the manuals. This is not particularly uncommon for refrigeration piping work as moisture, air, and dirt can cause numerous problems including compressor and motor failures.

What may not be as obvious to someone new to R410 system is the precaution to not mix tools used on systems with other refrigerants, especially R22, with the tools used with R410 equipment. This is because the refrigerant oil used with other refrigerants will react with R410 and create sludge and other problems in the piping circuit and compressor, leading to failure.

Tightening the Connection

Every Mitsubishi manual I have looked at:

- Specifies that a small amount of ester oil, ether oil or alkylbenzene be used to coat the flare and flanges before assembly. For an example, see Section 4.0 on page 7 of the *Mitsubishi Branch Controller Installation Manual* in *Appendix 2*.
- Cautions that the oil lubricants used for this purpose are different from the lubricants used with R22 and that using lubricants that are usually used with R22 systems (mineral oil) will cause serious problems in an R410 system. For an example, see Section 11 on page 4 of the *Mitsubishi Outdoor Unit Technical Service Manual* in *Appendix 3*.

Most of the Mitsubishi manuals I have looked at call out using two wrenches on the refrigeration fittings. For an example, see Section 7.1 on page 10 of the *Mitsubishi Indoor Unit Installation Manual* in *Appendix 1*. In some instances, torque wrenches are mentioned but I found no specific torques called out for the flare nuts.

Vibration and Stress at the Point of Connection

Most of the manuals I looked at indicated that the tubing should be supported with-in approximately 20 inches of the point of connection to the equipment so that there is no load imposed on the connections. For examples of this see section 4.1.7 on page 7 of the *Mitsubishi Branch Controller Installation Manual* in *Appendix 2* and section 7.1 on page 10 of the *Mitsubishi Indoor Unit Installation Manual* in *Appendix 1* . Generally, this seems to be complied with as can been seen from Figure 2 and Figure 3. That said, there are some issues that may require additional attention (beyond the insulation issues, which are not the focus of this memo).

The obvious issue is that there is at least one instance so far where lines are not supported with-in 20 inches of the line, as can be seen in Figure 3 where the lines associated with the twinning kit connect to the branch controller. This is a clear deviation from the Mitsubishi requirement and should be corrected.

What is less clear is what happens if the equipment is supported in a manner consistent with the general recommendations of the Mitsubishi manuals and the piping is braced in a similar manner,

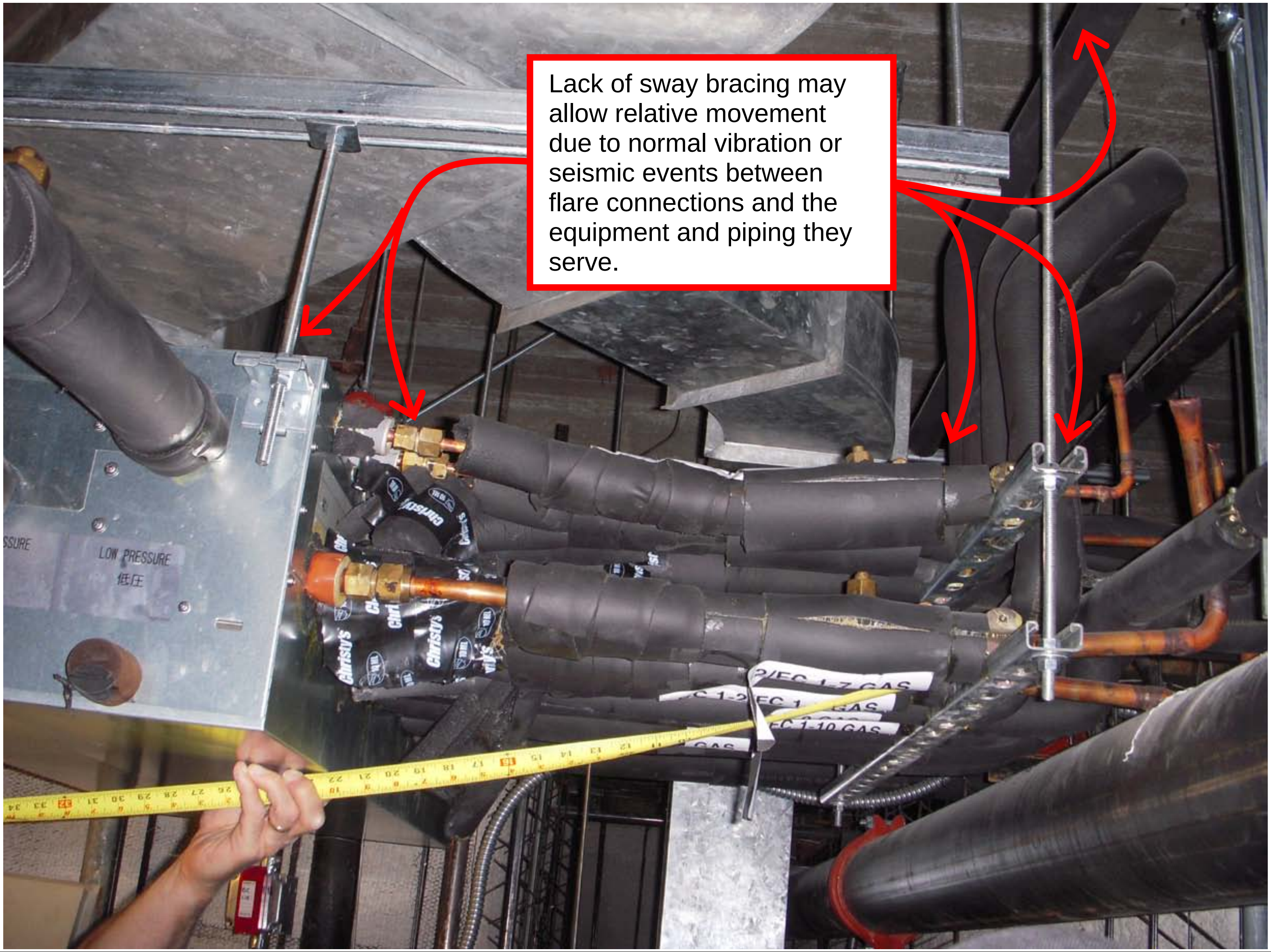

Lack of sway bracing may allow relative movement due to normal vibration or seismic events between flare connections and the equipment and piping they serve.
LOW PRESSURE

Figure 2 – Law Building Branch Controller Installation over Janitor's Closet

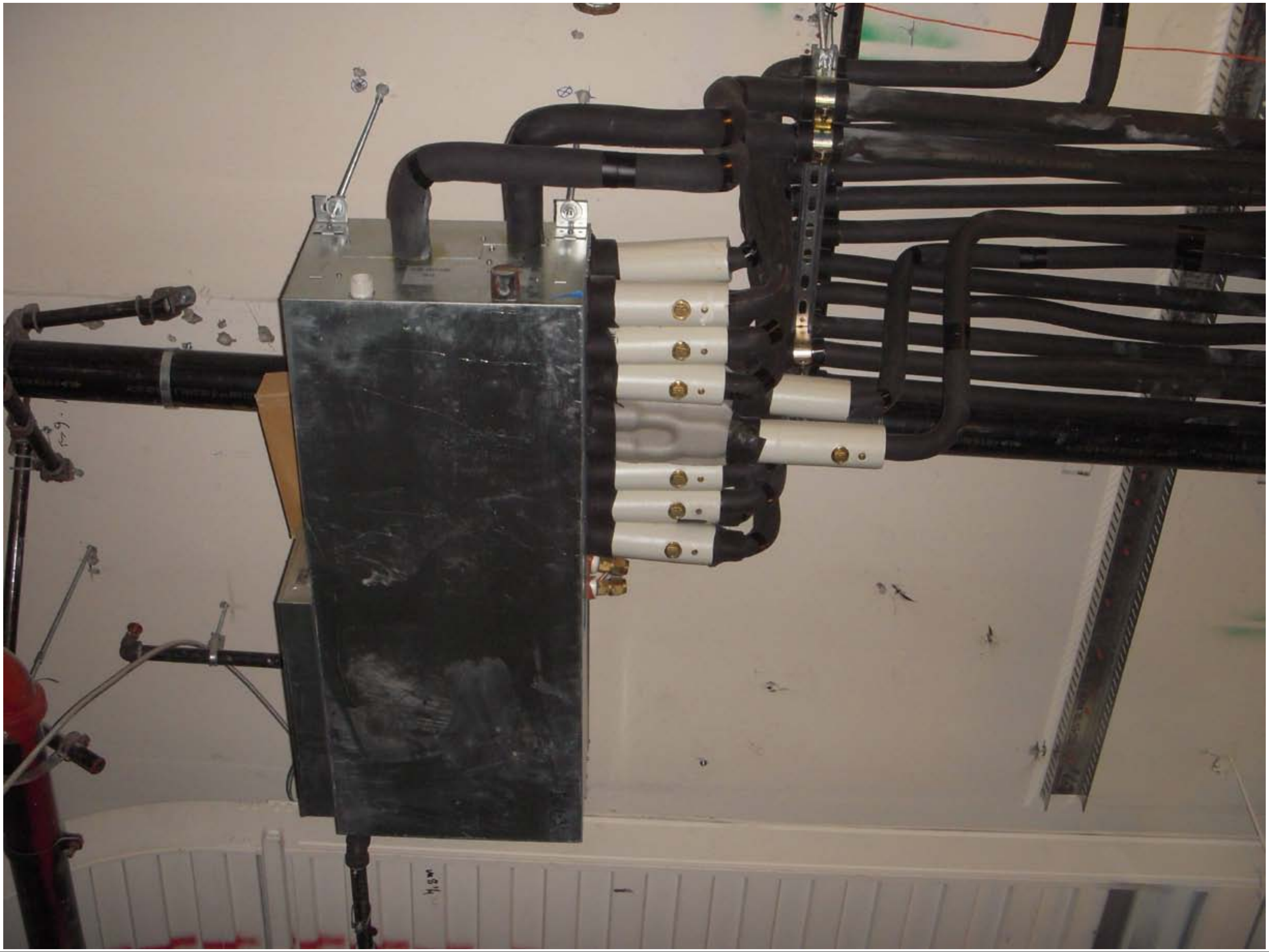


Figure 3 – Law Building Classroom Branch Controller Installation

but details of the installation still allow relative motion between the pipe and equipment. The installation illustrated in Figure 2 is an example of this.

Specifically, the branch controller support is similar to what is depicted in the sketch on page 4 of the installation manual. And the pipe trapeze is generally with-in the specified distance from the controller. But, because there are no sway braces, it is possible for the branch controller to move, thus moving the piping assembly and vice versa.

If such motion occurs, the angles between the piping and point of connection to the branch controller tend to change, which will place stress on the joints and could potentially cause a leak. Thus, the installation does not seem to comply with the stated intent of not placing a strain on the connections.

While large motions are unlikely unless there is a seismic event or the equipment is bumped by someone accessing it as they crawl through the access opening and around the unit on the ceiling to service it, they are also not out of the question. And smaller movements are likely due to vibration from the equipment operating and in the building structure.

Siesmic restraints would likely solve the problem as they would eliminate sway, especially if they were rigid vs. cable restraints. But for some situations like the one illustrated in Figure 3 and possibly, the one illustrated in Figure 2, the dimensions from the unit to the ceiling may be such that a seismic brace is technically not required. This means that it may be necessary to add sway braces to the branch controllers and pipe supports simply to ensure the intent of the Mitsubishi installation instructions are met and not rely on the seismic code requirements to address the issue.

Conclusions and Recommendations

Based on our research I have reached the following conclusions and make the following recommendations.

- Verify that the contractors are aware of the details of the Mitsubishi requirements for flare connections and have them certify that they are complying with those requirements.
- Ask the contractors to provide a submittal on the oil they are using to lubricate the flares when they make them up for verification and record keeping purposes.
- As a part of the inspection process, prior to pressure testing and evacuation, have the contractors disconnect flare connections selected at random by the inspector to demonstrate that they are in alignment with no loads applied to the joint.
- Have a Mitsubishi Factory Technical Representative review the installations depicted in Figure 2 and Figure 3 to determine if additional bracing is required in their opinion, to comply with the intent of their requirements to prevent loads from being applied to the flare connections. If their conclusion is that additional bracing is required then this should be rectified by the contractors as part of the contractual requirement for complying with the manufacturers recommendations. If Mitsubishi thinks the installations are adequate, consider having the contractors provide additional bracing as an extra if the units will not be braced to deal with seismic concerns.
- Develop a log to track the details of flare joint failures to see if there is any pattern that emerges and thus would point us towards additional investigation or mitigation. Items to include are:

- Date and time the leak was discovered
- Date and time the leak was corrected if different from the date and time of discovery
- Technician doing the work.
- Note if the leak was associated with piping or equipment installed under the current contract or a previous contract.
- Leak location, including the reference number of the piece of equipment where the leak occurred and the floor and approximate location on the floor (room number, column line, etc.)
- Specifically, which fitting was leaking; for example, suction line flare connection to branch controller or suction line flare connection to line set or brazed connection in piping run to indoor unit.
- Corrective action taken.

These recommendations will be reflected as action items on the CACEA portal. The action items will reference this report and related appendices for details.

David

Senior Engineer – Facility Dynamics Engineering

Appendix 3 – Economizers Integration with VRF Systems

David Sellers

From: Thomle, Adrienne (MN10) <adrienne.thomle@honeywell.com>
Sent: Friday, November 18, 2011 1:38 PM
To: David Sellers
Subject: Re: Following up

David,
It was a pleasure to meet you too. Thanks for the information. I will look it over and get back to you. And if you have further questions please call or email me.
Have a great Thanksgiving,
Adrienne

From: David Sellers [mailto:dsellers@facilitydynamics.com]
Sent: Tuesday, October 25, 2011 11:17 PM
To: Thomle, Adrienne (MN10)
Subject: Following up

Hi Adrienne,

It was nice to meet you last week; sorry for the delayed response. I've inserted the slides I have on bees, which came from public domain web sites. There are some other very colorful pictures at the Ace Clip Art site listed on the first slide. There are some really amazing and sharp pictures that are copyright protected at www.thehoneygatherers.com, a site by Eric Tourneret, a photographer who has been studying them for a while now.

With regard to the W7212 integration issues I have been investigating, what follows is pasted in from an e-mail discussion I had with one of the VRF manufacturers who came across the VRF, the Good, the Bad, and the Ugly – Cx Perspective thing I did with Mark and asked me a few questions. I include it because it's pretty much my thoughts based on what I know so far and I thought you might find it to be of interest.

Please bear in mind that anything that may seem like a criticism is not a criticism of your product. It's a very cool product that obviously has had a thought of thought put into it and really works. The issues I have are with how people are applying it and some of the field issues that I think are important but which I think are being ignored because, even though the economizer concept is simple, making it work is actually quite complex.

I've also attached a .pdf of the VRF slides since I reference some of the stuff in them in this as well as the wiring diagram I developed to wire up my mock-up.

1. ASHRAE 90.1 appears to have an economizer requirement based on an individual fan cooling *unit capacity* greater than or equal to 54,000 Btu/h. Under 90.1, economizers would be required less often than as required by Title 24 below correct?

[David Sellers] I think it is correct but to be honest, I am not a Title 24 expert. I would suggest you ask Mark Hydeman, who was the person that hosted the class. You may know him but if not, I can get you his contact info.

2. California Title 24 requires economizers when the *system capacity* exceeds 2500 CFM or 75,000 Btu/h. Basically, any system over 6.25 tons, correct?

[David Sellers] I also believe that is true, but ditto above.

3. California interpretation:

NOTE: Economizers shall be required for systems with single units, units in series, and multiple units in combination that equal to or exceed capacity listed in section 144(e)

of the 2008 Building Energy Efficiency Standards. The Performance Compliance Method with use of a computer compliance program may allow you to opt out of the economizer

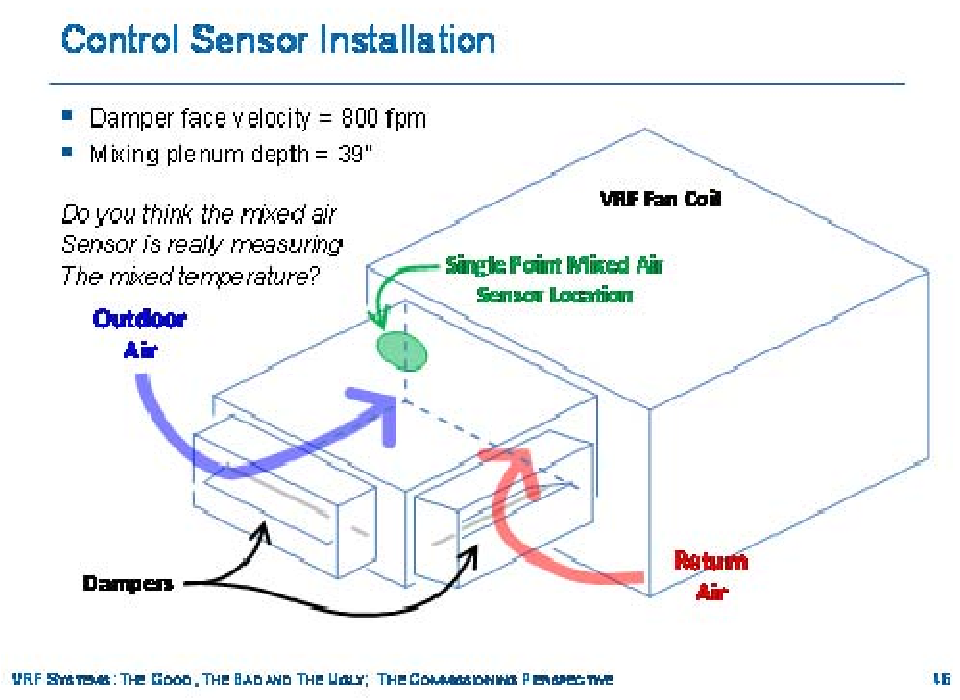
requirements if efficiencies are met. The question here is do you have a sense of the percentage of VRF projects that require economizers vs. the percentage of projects that opt out

with the computer compliance program?

[David Sellers] I don't but if anyone would, or would know who would, I bet it would be Mark. Ruben Willmarth may also know, but I suspect that might not be an option for you. All though, this may be an issue where you would stand united vs. as competitors.

4. From your presentation it appears you favor having the OSA sensor (enthalpy or temperature) remote upstream from the mixing box for optimum control.

[David Sellers] Not necessarily. The sensor I worry about the most is the sensor that controls the economizer; i.e. the sensor measuring mixed air temperature. My point is that (I know this from experience and measuring it) the temperature and velocity profile in a mixed air plenum, even a small one, can be quite stratified, and also quite dependent upon damper position, especially if the point you are looking at is immediately downstream of the damper location, meaning no time for mixing to occur. What that means in the context of the example in the slide below is:



- ***The air temperature at the sensor location I show (the green circle) when the economizer is in some modulated state, is likely closer to the OA temperature than not and the temperature on the side of the plenum near the return damper is likely closer to that.***

- ***The shape of the temperature profile will vary with damper position. At high return air flow, the return temperature will be reflected further across the plenum than at low return air flows and vice versa.***

- ***The flow profile will vary with damper position. If you are on 100% return air, I would not be surprised to see higher velocities (more flow) on the side of the plenum closer to the return damper. On 100% OA, the velocities will tend to be more uniform in this particular configuration.***

- ***The velocity and temperature profile variation will vary with mixing box configuration.***

- ***The actual mixed air temperature is a function of both the air temperature and the mass flow rate at that temperature. An easy way to visualize this is to imagine mixing 99 gallons of 100°F water with 1 gallon of 50°F water. The result is 100 gallons of water that is at a temperature closer to 99°F than not. It's not 100 gallons of water at 75°F, which is the average of the temperatures.***

- ***For an economizer to deliver the intended benefit, it has to know the true mixed air temperature. In the situation above, a single point sensor will probably be wrong most of the time and even an averaging sensor will be wrong a lot of the time because of the flow stratification. You might be able to get the single point sensor to work if you did a lot of testing (check temperatures at different points with different damper positions when it was cold enough outside to deliver meaningful information and then use the spot that is most representative of the average under all conditions – if such a spot even exists). But a guy with no support and a pile of parts and an edict to " get this installed as fast as you can because we're over budget on this one" probably will not do that.***

- ***There are ways to mitigate the problem a bit, one that comes to mind that might be easy to do for this particular situation would be to put the economizer someplace else besides bolted up to the unit so there is distance for the air to mix. If there were an elbow or two in between, so much the better.***

The other point with regard to the location of the sensor controlling the economizer is the decision regarding whether it should it be ahead of the cooling coil or after the cooling coil. The Honeywell literature basically says either will work but ahead of the cooling coil provides the most savings. All of that is true but there is a lot more to it (my opinion) than that.

If you put the sensor controlling the economizer ahead of the cooling coil (in the mixed air plenum), it will control the economizer independent of any influence from any cooling provided by the refrigeration system. Thus, it will deliver an integrated economizer cycle, assuming the refrigeration is controlled by something else, like space temperature or discharge temperature. In other words, you will continue to stay on 100% outdoor air until the change over sensor takes you off of the economizer cycle and the refrigeration equipment will make up the difference when the OA is not cool enough to satisfy the load in the space.

For the Honeywell controller, there is no set point adjustment and also no mention of the set point the controller shoots for when it is controlling the economizer dampers unless you read the fine print in the test procedure, where it sort of alludes to it. But if you experiment with the

controller, you can discover that it is 55°F, which tends to be the "generic" discharge temperature we use in our systems and which will be about right for most commercial buildings.

So, with any economizer process, you will end up at 100% outdoor air when the outdoor air temperature equals the set point of the economizer control process. Meaning, that for the Honeywell controller, you will be at 100% outdoor air when the outdoor air temperature reaches 55.

With an integrated economizer, if the outdoor air is above 55°F and you have a design load internally, you will not be able to meet the load and the refrigeration will have to run,. But the load on the refrigeration system will be modest, at least initially (which is the whole idea of an integrated economizer). For instance, if its 56°F outside, the refrigeration system only has to drop the temperature 1°F.

In contrast, if you locate the sensor in the discharge of the cooling coil, when the refrigeration cycles on because the OA cannot meet the load, then the sensor will see colder air than actually exists outside and will tend to drive the dampers closed, which will generally provide a non-integrated economizer cycle. (A non-integrated economizer quits using outdoor air if the outdoor air is not cold enough to handle the load. Generally this means the cycle is terminated if the outdoor air temperature rises above the required discharge temperature for the economizer controller.)

So, for a non-integrated economizer cycle, when it got to 55°F, you would be on 100% outdoor air. In a perfect would, if the system was designed to handle the load with 55°F air, you would be O.K. But if the outdoor air temperature got to 56°F, you would no longer meet the load and the refrigeration would have to run. For most non-integrated economizers, the decision to terminate the economizer process at this point is proactive; i.e. there is a control function that monitors outdoor air temperature and compares it to the set point for the mixed air control loop (or discharge control loop if that is what is controlling the economizer), and if the loop set point is above the OAT, it terminates the economizer.

The Honeywell approach mimics this reactively by virtue of where they locate the sensor, as described above. The problem is, the instructions don't really discuss this, they just say either location works but the location of ahead of the coil (integrated economizer) will deliver the most savings. That probably is because the person writing them understood all of that and didn't realize or actually believed everyone in the field would know that too, but they don't.

The other issue here is that if you provide an integrated economizer with a refrigeration system that is not able to turn down, you will end up short cycling the compressor and ruining it during mild weather because there is only a modest load on the coil.

So, for instance, if you have a 5 ton package unit that has one step of capacity control, "On" or "Off", then, when you need 55°F and its 56°F outside and the integrated economizer has you on 100% outdoor air and the OA cannot handle the load, the compressor will cycle on. But since the load is only a 1°F Δt (56°F to 55°F), 5 tons will be way more than you need and the compressor will stop as soon as it starts. But since you need it, eventually it will start again; either the

discharge temperature it is controlling to will go back up as soon as it cycles off, or the space temperature it is controlling to will not have been dropped enough to satisfy the call for cooling by the short burst of cold air.

So, bottom line, going to an integrated economizer on a package unit can be a bad idea. All the energy you save with the economizer will be eaten up in compressor replacement costs or by hot gas bypass operation if the system has it.

So, for me, in the context of the current discussion, there are two issues here. One is that the Honeywell instructions make no mention of this, at least none that I saw. They basically say either location will work and the location that would deliver an integrated economizer cycle will save more energy. So, someone trying to do the right thing (install an economizer to save energy) is likely to put the sensor in a location that will eventually destroy the compressor on a packaged unit with no turn down capability (what you tend to get in a low bid environment, which is how folks tend to buy them). Or it will waste energy by causing the hot gas bypass to run if the system is equipped with that.

From the VRF side of things the issue (for me) is this. There is a perception out there, at least from what I can tell (and I say this having ask folks and because I had it too until I sat down and talked to Ruben) that VRF systems have infinite turn-down capabilities. From what I know now (and your equipment may be different), that's not true. At the fan coil level, you are looking at about 25% of total capacity as the minimum load you can run at; at the system level, maybe 19-20%. So that means you could have the same sort of issue if all of the fan coils happened to see a similar load profile and their economizers unloaded them at about the same time. Not as big a deal I suspect on a system with some perimeter loads and internal loads and some diversity. But I think a conceivable possibility for a system that happened to serve 100% internal loads with the same load profile.

A related problem (that shows up towards the end of my slides) is that if you put in a 4 ton fan coil for a 1 ton load, you see major space temperature swings as the control algorithm tries to handle the load without being able to turn down as necessary to meet it. I think we should be able to engineer our way out of that one; for instance, size the unit you install for the current load but provide wire and line sets that will handle the potential anticipated future load so you can replace the fan coil unit with a larger one if it ever happens (I know it's probably a bit more complicated than that, but I bet we could do a better job than we are doing).

But folks seem to have stopped engineering. So, on at least one campus, where one of the major reasons they were going to VRF systems was because the consultants kept putting in 600 ton chillers to handle 300 ton loads that had about a 20 to 1 or more turn down ratios, they now have 4 ton fan coil units put in to serve 1 ton loads (because it might be 4 tons some day; key words there are "might" and "someday"). So, they switched the problem from a central plant to fan coils above inaccessible ceilings and condensing units no roofs with difficult access routes.

The OA sensor location is a different discussion. In the example, we initially found the enthalpy sensor basically tossed into the duct through a hole that had been punched with a screw driver and not sealed very well with the little lovers on the sensor laying on the bottom of the duct. The

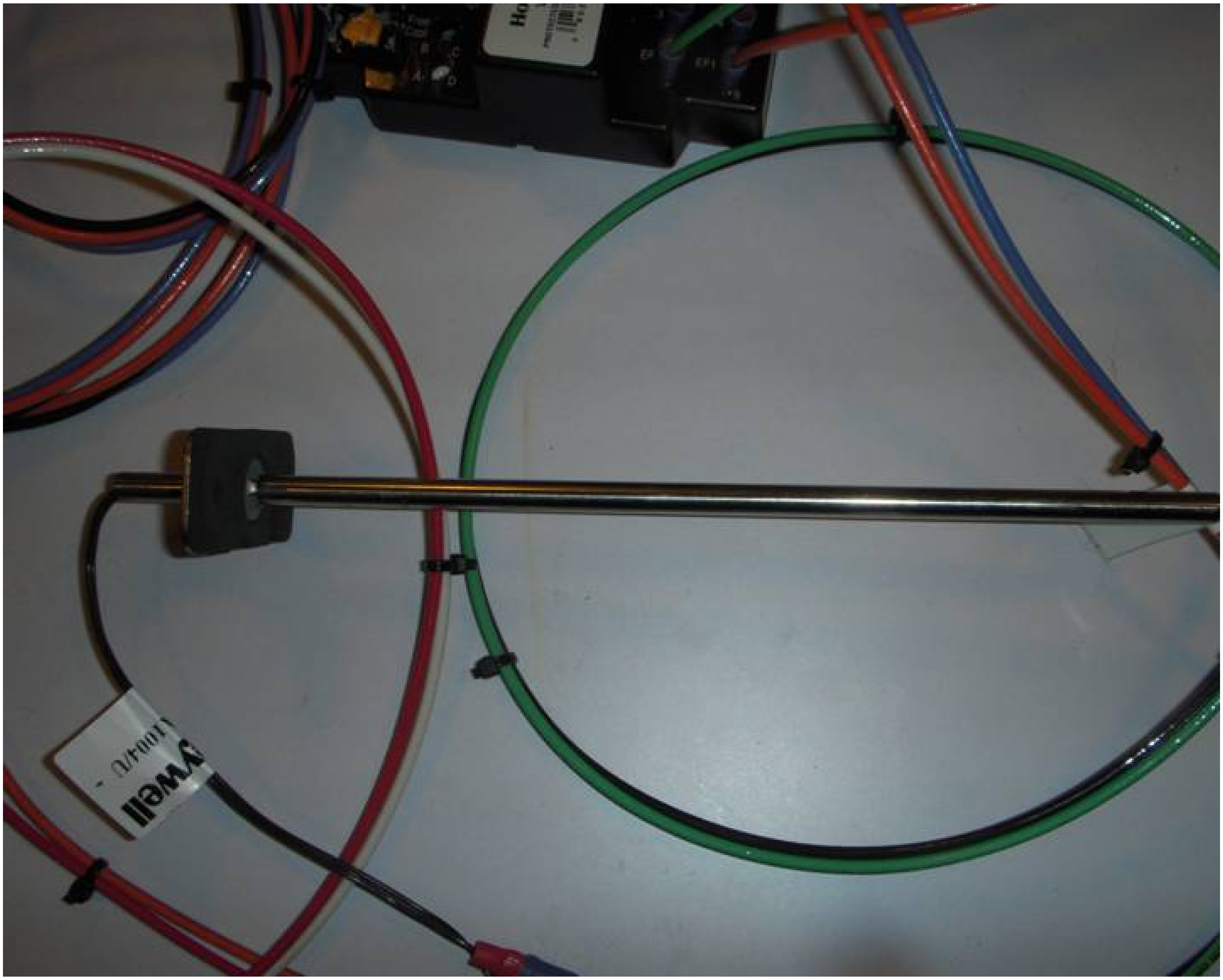
improved mount (bolt it to a plate) helps since at least the sensor is now more likely to see air flow.

But one still has to wonder how responsive the sensor will be and how good of a job it will do with the little louvers vs. a sensor directly exposed to the air stream. Probably better than the "clicks-on" which is the lowest cost approach so guess which one you will get on a low bid job or a "replace that as cheap as possible" maintenance order. But the "clicks-on" (and the dry bulb sensor Honeywell makes as an option) are likely more persistent than the enthalpy sensor because of the issues associated with measuring humidity, at least in my experience (see attached NBCIP reports, which document what anyone out in the field knew from experience) (we probably would have named the same names).

In this case, the OA duct is actually a duct from the discharge section of an economizer equipped AHU vs. a duct to a louver on an exterior wall some place (another discussion point, that I will reserve for our conversation unless you want me to elaborate before then; I would not be surprised if it happens a lot). What that means is that the OA duct is positive, not negative

In addition to the change over sensor issue I am about to elaborate on, this means the OA flow is a function of what the source unit and other zones fed by the source unit are doing. So, setting up the minimum OA flow for any given fan coil unit is a lot more complex than it would be if there was a duct to a louver on the wall. And it means that the procedure outlined in the W7212 literature for setting it up would flat out not work. It also means that if you don't close the OA damper on the VRF unit economizer when the fan is off, you will blow cold air through the zone, like it or not.

In any case, what that means for the change over sensor is that you don't have to worry so much about "faking it out" due to drawing air in through a hole to the return plenum. How critical that is comes down to the pressure in the OA duct (positive or negative) and the type of sensor you use. Honeywell, as near as I can tell, considers both of the sensors in the pictures below to be equivalent for the mixed air sensor (I realize we are talking about the change over sensor here, but the same concepts apply).



I'm pretty sure there is a potential installation problem associated with the first one that would mean it would see a lot of air from the plenum around the OA duct if the OA duct was negative. And I think it is the least expensive one, which means it's the one you may be more likely to get.

That said returning to the change over sensor, as long as it's really seeing OA, then it does not matter much where it goes as long as it is in the OA stream. I worry more about the reliability of a sensor that has too measure humidity (enthalpy sensors calculate enthalpy based on temperature on humidity as far as I know; I don't think we have a technology that measures enthalpy directly). So, I tend to side with Steve Taylor's conclusion about using a dry bulb based change over in his ASHRAE journal article (copy attached if you are not familiar).

5. From your presentation you have concerns about the mixed air sensor location in the mixing box. Could there be an optimum location centered in the box or did the box manufacturer simply place it on the end?

[David Sellers] See preceding; the box manufacturer does not place it, the field guy does. The Honeywell information recommends general locations (ahead of vs. after the cooling coil) but not

specific guidance relevant to the stratification issues I discuss although I think they allude to that at one point.

6. You were rightfully critical of the interface documentation. After reviewing the Honeywell data and a particular manufacturer's interface drawing and actual unit wiring configuration, I can see there is a real need for accurate interface diagrams.

[David Sellers] I made one for a generic case that is on my blog; copy attached, including the CAD file. Feel free to use it if it's helpful. It works; I had it on my drafting board for a while and just used it in a class yesterday for a lab exercise. But you have to understand all the details and get them right, which is where I plan to head with my blog string. We (as an industry and a society) have got to quit screwing things like this up.

I also was pretty critical of access issues, but if you heard me do the talk, you would have heard me say that the VRF examples were just indicators of an endemic problem out there. We have got to make the technology serviceable, including the economizer, serviceable, if we want the benefit to persist. You may have tried working on one of these things that is 15 feet above a hard ceiling with an 18" square access opening that is 8 feet above the floor, so you know what I mean. If not, you may want to try taking the economizer check out procedure in the W7212 manual and the service instructions for one of your units and go try to do them in such a situation, as I think it will be enlightening.

If we can dedicate server rooms to our computer systems, electrical closets to our electrical distribution systems, and communications closets to our phone systems, maybe we need to think about making branch controller rooms for projects that use that technology and also think about how we locate the fan coil units, especially the economizer equipped fan coil units, a bit more.

Thanks for your interest and help.

Anyway I hope this is not "more than you cared to know about elephants" as Al Black, a mentor of mine was fond of saying.

Thanks for taking the time to talk at lunch. I enjoyed meeting you and hope to cross paths again.

Best,

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