VRF 101: Managing Expectations

I am located in Southern California and a former manufacturer's representative for two well-known variable refrigerant flow (VRF) manufacturers, a Life Member ASHRAE and a lawyer. As a result, I have been exposed to design, installation, engineering and layout issues regarding VRF. I would like to expand on a few points mentioned in the excellent column by Michael Gallagher, P.E., Fellow/Life Member ASHRAE, "The VRF Learning Curve," in the January 2023 issue of *ASHRAE Journal*.

As-built drawings should be signed by the contractor and submitted as a matter of record. The factory or manufacturer's representative should be required to review and approve the "as-builts" and calculate correct refrigerant charge based on those drawings. The as-builts should include distribution boxes and show their location because making connections or troubleshooting the distribution boxes is difficult without accurate as-built drawings, which should show condensing units and access.

Choice of manufacturers: there are over a dozen VRF manufacturers. The major players are represented by local manufacturers' representatives. VRF layout and specifications are typically done by the representative as a service to the engineer or design build contractor as selections are based on the manufacturer's unique computerized selection program. VRF systems are more complex than imagined.

Just because condensing unit size is small (4 tons to 20 tons) and multiple system evaporators comprise small fan coils or cassettes, engineers and contractors underestimate the complexity of these systems. Choosing manufacturers should be brand-specific. The engineer or design build contractor should choose well represented brands for their particular area. Representative expertise is critical. Factory support, local factory training, warranty and parts availability are also all to be considered. Increasingly, VRF is being used on larger class A projects where the owner's expectation on behalf of their tenants is very high. If the contractor cannot get field support or parts like compressors or circuit boards, the owner is not going to be happy.

Likewise, choosing a contractor is most important. If considering multiple contractors for a project, the engineer should insist on meeting the contractors' project manager and field foreman and start-up technician. The engineer should get a list of similar projects, with information on the equipment brand, owner's representative and manufacturer's representative involved in these projects and should really check them out. Owner impressions are particularly valuable as they represent the owner's expectation as to equipment brand, contractor qualifications and performance, parts availability and representative support.

It is up to the engineer or design build contractor to really understand access required with a VRF installation. On many projects, access is not coordinated with the architect and general contractor. If the engineer has concerns regarding access, they should go on record in writing about their concerns (very helpful in case of litigation).

Inspection/supervision contracts between the engineer and architect or owner are a frequent source of litigation, as contract language is often poorly written. If the engineer is not taking an inspection/supervision contract, they should notify the architect in writing, outlining areas the architect is *not* responsible for. If an inspection/supervision contract is part of the job, the engineer should specifically define scope and design areas the engineer is and is not responsible for.

For instance, would the mechanical engineer be responsible for seismic anchorage details, pipe fastening and support, condensate pump location and drains and structural and acoustical issues if there is no sound consultant on the project, power and control wiring, access requirements and interference with other trades under an inspection/supervision contract? VRF installations have many players, all with differing levels of expectation, so when push comes to shove, the engineer is wise to define and limit their exposure.

There may be situations where the engineer should use a different system—where VRF is not easily understood, will not be maintained, is in a remote location or where access is an issue (for instance, in hotels, condo units or schools). Perhaps hydronic heat pumps for condo units or schools and chilled water/hot water fan coils for hotels, in lieu of VRF, would be advisable and less problematic.

VRF is new to North America. In many cases, it can be a good choice. It is, however, vital that the architect, owner, general contractor and engineer control the dialogue and manage expectations when considering VRF.

George Orff, Life Member ASHRAE, Laguna Beach, Calif.

GALLAGHER RESPONDS

Thank you for your comments, George. As we have both indicated, VRF is not the sort of system that lends itself well to the design professional losing contact with the project once the initial design is complete. It is particularly important for the engineer to review an accurate "as-built" piping drawing when the piping is complete, and to at least spot-check a system or two to make sure the as-built drawings are accurate—as well as verify that the final result was actually run through the manufacturer's software. This as-built then needs to be suitably memorialized so subsequent TI changes and service work are based upon correct information and a proper set of drawings.

VRF also rewards getting the entire design and construction team selected and together early in the process. Most VRF system issues can be avoided if the entire design and construction team is involved throughout the project.

Michael Gallagher, P.E., Fellow/Life Member ASHRAE, Santa Fe Springs, Calif.

Under Pressure: Steam Drainage Systems

The article "Understanding Steam Drainage Systems" by Gene Nelson, Life Member ASHRAE, in the February 2023 issue of *ASHRAE Journal* highlights several important issues pertaining to steam condensate recovery piping systems. I commend the author for a thorough and well-researched review of two-phase condensate flow characterization, air venting and pressure gradients within steam condensate piping systems.

However, on the topic of dry-closed condensate return pipe sizing, the author conflates gravity flow and steam pressure motivated sizing practices. Of particular concern is the recommendation to use "… pressure drop rates consistent with gravity flow…" for dry-closed returns and the advised caution against pipe sizing based on flash steam flow and maximum velocity, without consideration for slope.

Dry-closed condensate return pipe sizing is based on a continuous pressure differential from the condensate inlet to the discharge point, not pipe slope. Although it is common practice to slope this piping in the direction of flow for sediment removal, steam serves as the motive force for conveying condensate through the system rather than gravity.

Pressure drop rates listed in *ASHRAE Handbook—Fundamentals* Table 37 (determined from the Darcy-Weisbach equation) are appropriate for this closed flow condition. The author's proposed revision of Table 37 pressure drop rates to align with corresponding gravity drainage slopes is not applicable to dry-closed condensate return piping.

Additionally, the author's suggested modification of conventional dry-closed return pipe capacity tables to account for slip velocity (and reduce the risk of slug flow) using the provided curve fit equation should be considered with caution. According to the research project cited in the article, this method is subject to appreciable error and further study was recommended. Alternative slip velocity correlations offering accuracy improvements have been developed and warrant further investigation.

Traditional pipe sizing methods offer a practical and empirically proven means of preventing water hammer in steam condensate systems. For example, flash steam velocity limitations for condensate piping are kept significantly lower than that of steam supply piping, tacitly acknowledging the increased risk of water hammer with lower quality steam. Of course, accounting for all variables in our computations is often desirable, but inherent errors and complexity trade-offs must be carefully considered against long-standing practices.

Kevin LaPlante, P.E., Member ASHRAE, Concord, N.H.

NELSON RESPONDS

Mr. LaPante's letter offers some interesting concerns and discussion points regarding pipe sizing methods for dry-closed systems. There are multiple ways to use Table 37. *ASHRAE Handbook—Fundamentals* does not offer much explanation on how to use Table 37 and leaves the interpretation of what pressure drop rates to use up to the designer.

The continuous pressure differential method mentioned by Mr. LaPlante may have issues with potential of liquid backup and slug flow, resulting in water hammer due to variable steam flow and pressures from cycling steam traps and higher steam velocities that may be greater than the slip velocity ratio.

Depending on how the traps were selected, trap flow may not be sufficient when the backpressure varies when using the continuous pressure differential method. Depending on how the common drain pipes were sized, there may be a large slug at the discharge to the receiver using this method. By limiting the slug flow to just the trap discharge line and by using a common drain line based on gravity flow as suggested by my article, many of the issues described above can be minimized.

I agree that the Darcy-Weisbach equation can be applied when the fluid is in a constant state (liquid or vapor) with a known friction factor. Using a continuous pressure differential method with steam motivation, the fraction of liquid and flash steam flow changes continuously, and it is difficult to predict the fluid properties (density and viscosity) at any one point. Using a stratified flow regime as described in my article provides a more predictable pressure drop calculation for the common drain line because the fluid properties do not change much.

I agree that the results of the slip velocity method presented in ASHRAE RP-167 could be more conclusive. My interpretation of RP-167 along with the void fraction calculation offers guidelines for further research and provides a conservative correction to Volume Ratio Equation 26 (*ASHRAE Handbook—Fundamentals*, Chapter 22) used in Table 37 in determining steam flow areas.

I believe the traditional tables can be used successfully, provided the designer understands the assumptions behind the tables. My suggestions to improve Table 37 are meant to provide better guidelines to the designer in making good judgments, especially in selecting a pressure drop rate for the common drain line.

In conclusion, the approach described in my article provides a more conservative approach at the expense of larger common drain pipe sizes. Pipe pitch plays a very important role on what pressure drop rates to use when gravity is the motive force. I hope that my recommendations described in my article are considered in future research and development of better guidelines for designers.

Gene C. Nelson, P.E., Life Member ASHRAE, Madison, Wis.

CO_2 Taking Too Much Heat in Climate Change Conversation

Regarding the article by Thomas Lawrence, Ph.D., Fellow ASHRAE, and Costas Balaras, Ph.D., Fellow ASHRAE, in the February 2023 issue of *ASHRAE Journal*—first and foremost, carbon dioxide (CO_2) is *not a pollutant*. This determination by bureaucrats is a gross violation of science. CO_2 is necessary for life on planet Earth. Photosynthesis, plant life and the creation of oxygen does not occur without CO_2. Regulation of CO_2 is best left to the oceans and plant life, not bureaucrats.

CO_2 is a small factor in supposed global warming compared to water vapor, solar activity and other contributing factors. Never do the eco people mention their "acceptable" levels of CO_2—100 ppm? 200 ppm? Or that good greenhouses need 800 ppm to 1,400 ppm of CO_2 (added into the greenhouses) to grow crops for consumption by humans and animals.

ASHRAE has made multiple errors from following bureaucrats with no responsibility—how about shut-off VAV boxes and reduced outside air causing *huge* claims for sick buildings in the late 1970s/early 1980s? The electric grid cannot provide power to electric cars and the proposed heat pumps. I live in Nevada where the utility must purchase 40% of the power from adjacent states.

All humans and animals emit CO_2. What is next? Will ASHRAE support the bureaucrats to eliminate human and animal life? Heat pumps, despite improvements, do not work below 32°F (0°C) without electric heat.

Karl M. Petroff, P.E., Member ASHRAE, Henderson, Nev.

LAWRENCE, BALARAS RESPOND

We appreciate your interest in the article and the opportunity to respond to points you raise. As a general comment, the authors have used and presented information and other arguments based on technical data and scientific knowledge from international resources, such as the Intergovernmental Panel on Climate Change (IPCC) of the United Nations. These are not "bureaucrats," but rather scientists whose careers have been spent studying this issue.

But first, let us consider the definition of the term "pollutant," as that was the key point of your lead-in sentence. A commonly accepted definition of a pollutant (in our paraphrase) is the emission of a substance that will have a negative impact on some aspect of the natural environment.

For CO_2 there are some potential positive factors, that you point out, but there are also negative factors, which you do not. Indeed, as you mention, increased CO_2 levels up to a point increase the photosynthetic potential of plants, which has been recognized as a possible benefit.

For a well-sealed agricultural greenhouse, the consumption of CO_2 by plants can decrease the CO_2 levels of the air inside that greenhouse to the 150 ppm to 200 ppm level (compared to the current concentration in the air outside a greenhouse that is in the range of the low 400s ppm). Greenhouse operators may therefore choose to add CO_2 to their air to help the plants continue growing. Hence, one may confuse what is an acceptable level of CO_2 in the range of 100 ppm or 200 ppm, as you mention in your response.

However, that does not recognize the reality that the actual ambient concentration in the earth's atmosphere now exceeds 400 ppm. In preindustrial times (before 1800), the CO_2 concentration was roughly 280 ppm, and based on the real-science ice core samples that we have it has not exceeded 300 ppm in the past 400,000 years. Thus, scientific evidence has clearly documented that volcanic activity or other natural phenomena other than human activity did not increase the CO_2 concentration to anywhere near the current levels.

Furthermore, solar activity is not a driving factor to consider since the amount of solar energy incident on the earth has actually slightly declined in the past few decades (see "Is the Sun Causing Global Warming?" from NASA: https://tinyurl.com/2p97y9e4). There is also clear scientific evidence that global ambient CO_2 levels of the 800 ppm to 1,400 ppm range have not been that high for at least 20 million years, while there is a strong scientific belief that these would be actually catastrophic for the environment and humankind.

The global environment is changing, and increasing temperatures are recorded throughout the world, with records from worldwide sources documenting global warming. Although CO_2 is not the only factor, it is recognized by world leading scientists who do this work and international organizations like IPCC of the United Nations as it being a significant factor.

The last half of your letter deals with many issues outside the topic of our article—for example, the thinking that ASHRAE "followed bureaucrats" when deciding on outdoor airflow rates for buildings. The reduction in outdoor air set by ASHRAE Standard 62.1 in response to energy concerns of the 1970s was, admittedly in hindsight, a mistake but this has been corrected and lessons learned in terms of taking the necessary precautions in the efforts to handle energy savings while securing the proper indoor environment.

On one of your other points, it is true that heat pumps' performance drops near freezing, but already heat pump technology is making good progress even in cold climates. In any event, there are different considerations and optimal solutions for different buildings in different climate zones. The issues related to how fast we should proceed with the electrification of buildings, transportation and the electrical grid by exploiting different solutions and technologies are key issues of the overall decarbonization discussion.

More energy efficient buildings can be designed, constructed and operated to have a much lower energy demand and rely less on carbon emitting energy sources. At the same time the electrical grid must be adapted to lower carbon emissions, but that is an issue beyond the topic of this article. All of these will take time but we also as a society need to move in the right direction.

Thomas Lawrence, Ph.D., Fellow ASHRAE, Athens, Ga.; Costas Balaras, Ph.D., Fellow ASHRAE, Vrilissia, Greece

What About Water Vapor as a GHG?

I read, with interest, the article by Dr. Lawrence and Dr. Balaras. I am 100% supportive of the role ASHRAE is developing to decarbonize buildings and appreciate the leadership both authors are exhibiting.

My only problem is this sentence: "Carbon dioxide has long been recognized as the most significant GHG…" This is categorically untrue. In fact, water vapor is the most significant and greatest quantity GHG. Even NASA has recognized that moisture and clouds could create significant impacts, both radiative and infrared feedback. They commenced a study of such in 2021, but have yet to publish results. And our climate models do not adequately reflect moisture or moisture changes.

It would be appropriate to say that carbon dioxide is the most significant anthropogenic GHG, although even that statement requires a comparison with water vapor, which currently doesn't exist. We do know that a 1 degree increase in temperature results in 10% more moisture in the atmosphere (think psychrometric charts). But it is uncertain the exact form (invisible gas, clouds) such moisture takes.

Tom Werkema, Member ASHRAE, Louisville, Tenn.

LAWRENCE, BALARAS RESPOND

We appreciate your interest and feedback on the article. First, let us state that we agree that the wording in that sentence should have stated that carbon dioxide is the most significant anthropogenic greenhouse gas emission. You do bring up the interesting point about water and water vapor in the atmosphere. Yes, water vapor does also help trap the emitted thermal radiation from the earth, as a greenhouse gas does. But water vapor in the form of clouds also can serve as a cooling effect by increasing the reflectance of incoming sunlight compared to most earth surfaces below the clouds (ice not withstanding).

Humans do contribute to a larger atmospheric level of water vapor through its release via things like electric power plant and air-conditioning cooling towers (or your boiling a pot of water for your spaghetti dinner at home). As you point out, more research and study is needed on the comparative effect of water vapor on the greenhouse effect, and in particular the relative contribution to any additional anthropomorphic water emissions.

Thomas Lawrence, Ph.D., Fellow ASHRAE, Athens, Ga.;
Costas Balaras, Ph.D., Fellow ASHRAE, Vrilissia, Greece ■

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