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Additional submitted attachment is included below.

Mitsubishi Electric Comments on VCHP Duct Losses, Effective Buried Duct R-Values, and Unfactored Variables

Heat Loss Equations Clarify Why Deeply Buried Ducts Makes Sense for All Ducted Systems

Originally submitted by Bruce Severance, Regulatory Compliance Engineer, March 24, 2020

Resubmitted to CEC Docket on AB3232 as a supplement to Mitsubishi Electric comments on why optimized HVAC installation on all ducted systems is so critical to "beneficial electrification"

INTRODUCTION

Mitsubishi Electric appreciates the Commission's efforts to mitigate the impacts of buildings on climate change and recognizes the importance of rapid mobilization strategies that produce measurable reductions in GHGs over the next thirty years as well as a broader transformation of California's economy to carbon free and carbon negative alternatives. On issues of climate mitigation strategies Mitsubishi Electric is an outspoken advocate. In June 2019, Mitsubishi Electric published "Environmental Sustainability Vision 2050" to clarify the company's stance on addressing long-term environmental issues. This corporate vision asserts that "The Mitsubishi Electric Group shall utilize diverse technological assets throughout wide-ranging business areas to solve various environmental issues, including climate change…" Mitsubishi Electric regards climate mitigation a primary mission and service to our customers, and in furtherance of the goals of the Paris Accords, we believe the climate science and desire to be reliable and consistent partners in the global climate mitigation efforts.

Supplemental Comments in Response to Commission Staff Response to Mitsubishi Electric 3-23 Submission on Duct Design and Ducted System Optimization:

In response to Mitsubishi Electric's March submission of comments regarding possible inaccuracies in the WCEC research and in the ACM effective buried duct R-values, CEC staff submitted a response with copies of the original 6-page paper (Griffith-Zuluaga 2004) upon which the effective buried duct R-values are based. This study used a finite element analysis to determine effective R-values of ducting buried in blown attic insulation, but then averages and generalizes the effective R-value based on most attics having a range of duct diameters with typical trunk and branch design. Based on this assumption, and the resulting average R-values, three "bins" or R-value levels are created for "partial", "fully" or "deeply" buried ducts are defined. With partially buried ducts, insulation depths are assumed to be within 3-1/2" of the top of the exposed duct, fully buried ducts are at least completely covered, and deeply buried ducts are buried by at least 3-1/2" of blown material. These assumptions are made "to simplify" and average overall duct system R-values, but the assumptions are inherently incorrect if the entire duct system consists of supply ducts that are no more than 8" in diameter, and all are deeply buried.

Mitsubishi Electric's original comment to the CASE Team addressed the WCEC research and the proposal that ONLY variable capacity equipment be subjected to buried duct requirements, and it used simple heat loss equations to illustrate how Chitwood's duct optimization techniques can reduce the typical 20% to 40% duct losses to a fraction of that. In light of Chitwood's research which the CEC has supported, the RACM tables are inaccurate because they assume trunk and branch duct design and adopt an averaging or simplification of actual R-values based on such assumptions that is inherently inaccurate and which discourages the high-efficiency alternatives illustrated in my March submission to the CASE Team. Although these heat loss calculations would need to be confirmed by more detailed FEA modeling, they clearly illustrate within a margin of error that the generalized effective duct insulation charts adopted by the CEC into the RACM (Tables 15 to 17), are not accurate relative to the original FEAs performed by Griffith-Zuluaga and others. They assume that the "averaging and simplification" of the R-values applies to all systems, even those with a small-duct, parallel ducting configuration, when they do not.

Furthermore, as illustrated below, the ACM charts err on the side of giving large trunk ducts a higher R-value than they in fact have, because they are averaged with more deeply buried smaller ducts, and this undue efficiency credit discourages the more efficient and less expensive Chitwood optimization method that the CEC should be attempting to promote in the interest of maximizing value to residents and minimizing peak loads on the grid which are primarily driven by residential HVAC loads. This duct design strategy is far more cost beneficial and goes further to mitigate grid harmonization issues, than awarding high EDR compliance credit to residential batteries as is currently the practice in the 2019 ACM. It merits closer examination.

The inaccuracies in the RACM effective duct R-value tables are therefore not trivial, but will predictably act to exacerbate the current grid harmonization challenges (duct curve slope and grid management) with which the State is currently faced. The inaccuracies should not be ignored or explained away with credible studies by reputable organizations which have made inaccurate assumptions that are detailed below.

Although the Griffith-Zuluaga paper assumes a lower blown fiberglass R-value of 2.5 per inch than our calculations based on Certainteed's specification of R-3.2 per inch, (used in our examples and corrected chart numbers), the principle inaccuracy of the chart simplification into three "bins" or R-value plateaus is still evident. Using the fiberglass R-2.5 value (assumed by Griffith-Zuluaga and adopted into theRACM Table 17 for R-4.2 ducts) Table 17 shows the same R-value for 4" ducts as for 10" ducts when deeply buried in R-49 (19 inches of R-2.5 insulation). However, the actual R-value of the 4", 6" and 8" ducts is R-27, R-22 and R-17 respectively. The 10" duct would have an effective R-value of R-12, just over half of the stated effective R-value. These figures assume the R-4.2 insulation would be slightly compressed where it meets the bottom chord, which is always the case in the field.

Similar inaccuracies appear in the Griffith-Zuluaga R-8 chart (RACM Table 15). Whereas the 4", 6" and 8" ducts are shown to have an effective R-value of R-26 when resting above the truss bottom chord and buried in 19" R-49 insulation (R-2.5/inch), the actual duct R-value accounting for compression of the R-8 duct insulation between the truss and the duct liner, is closer to R-25, R-20, and R-15 respectively. Only the 4" duct would be in the range of the stated effective R-value of R-26. The 10" duct is shown to have an R-value of R-18, when it would again have a little more than half of that, (R-10). The basis for these "simplifications" is explained in the Griffith-Zuluaga paper states near its conclusion:

> *"It was the goal of this study to look at enough scenarios to be able to make appropriate design recommendations. Guidelines have been developed to assess the effective R-value of a buried duct system. These became the basis for Table R4-12 in the 2005 Residential ACM Manual (CEC 2003) and are presented in Table 3. Simulation results from small ducts and large ducts were combined so that these guidelines are applicable to ducts of all sizes commonly encountered in residential applications. This simplification is valid since for a particular buried duct classification, the impact of duct size on effective R-value was found to be small."*[1]*

The problem with this conclusion is that it is not accurate even if we use the values and assumptions stated in their research. Using the Griffith-Zuluaga estimate of R-2.5/inch for blown fiberglass, the difference between the effective R-value of the 4” and 8” ducts is roughly 40% for both the R-4.2 and R-8 duct examples. This is not a “small” difference in R-value – at all. In the case of the R-4.2 chart, the 10” duct is awarded the same R-value as the 4” duct when it in fact would have well over twice the heat loss. Although one may question the accuracy of using simple heat loss equations to double check FEA modeling, it appears that after completing such detailed modeling, the chart simplification and false assumptions threw out their more accurate FEA modeling data. This simplification approach ignores LBL data that indicates that so called “thermal holes” create disproportional heat loss, a variable which doesn’t seem to be factored in any of the cited foundational research.

When the CEC is in possession of Chitwood’s system optimization research, it is hard to imagine why the advantages of parallel duct design has not been embraced or more overtly encouraged by the energy code when Chitwood’s Method is known to reduce HVAC loads so significantly. (Please reference the load calculations in the original paper submitted to the CASE Team in March 2020 which illustrated these potential savings below).

It response to this submission, Mr. Wichert of the CEC, also submitted a DOE-NREL paper entitled “Reducing Thermal Losses and Gains with Buried and Encapsulated Ducts in Hot Humid Climates” by Shapiro, Magee and Zoeller with contributions by Steve Winter and Associates published in 2013*[2]. Although this paper focuses on methods to deeply bury ducts in hot and humid climates while mitigating against potential condensation on the buried ducts, it also includes some tables on “effective and apparent R-values”, the latter accounting for heat transfer to the underlying drywall.

Although the research is detailed and employs LBNL’s THERM software to conduct modeling, it makes similar false assumptions by adopting the same “partial, fully and deeply buried” definitions developed by Griffith-Zuluaga, but applies them to each duct diameter individually, such that a deeply buried 16” diameter duct has a higher value than the deeply buried 4” duct. The resulting charts are counter-intuitive. A 4” duct buried in R-49 would have significantly lower btu losses than a 16” duct partially buried in R-49. But a closer examination of how they have applied the partial, fully and deeply buried classifications reveals that the charts assume that the 4” and 16” ducts that are “deeply buried” are both covered by 3-1/2” of blown insulation, as if one side of the attic has 23” of blown fiberglass and the other only 11 inches – which would never be the case in most conventional energy retrofit projects in California. The result of this combination of contrived definitions and R-values are tables that lack clarity and which are somewhat impossible to apply to real-world field conditions. There are no attics with blown insulation varying from 11" thickness to 23" under today's installation protocols, and the lack of explanation for the basis of the effective and apparent R-values shown in the tables is unintentionally misleading and extremely difficult to interpret for either regulators or energy analysts attempting to qualify projects.

Table 16. R-Values of Mounded-Buried R-4.2 Ducts Encapsulated in 1.5 in. of ccSPF

Duct Inner Diameter (in.)	$R_{effective}$	$R_{apparent}$
4	15.2	15.2
6	18.7	18.5
8	21.6	20.9
10	24.1	22.9
12	26.2	24.6
14	28.1	26.2
16	29.8	27.5

The section drawing illustrated in Figure 45 (from page 55, below) shows the intended practice of blowing closed-cell polyurethane foam over flex ducts and then burying ducts in mounds of blown insulation. Although it is clear that the closed cell foam encapsulation is an experimental procedure to allow deeply burying ducts in hot and humid climates, and this practice is not intended for California's relatively dry climates, the same assumptions of "mounding insulation" seems to been applied to the modified charts submitted to the CEC by Steve Winter and Associates in response to their request for clarification. Obviously, a more customary practice is to blow a more consistent depth of insulation across the ceiling to obtain credit for the ceiling insulation either as an upgrade measure through incentive programs such as California's Energy Upgrade Program or to receive EDR compliance credit in new construction. Also, California is considered a dry climate, and

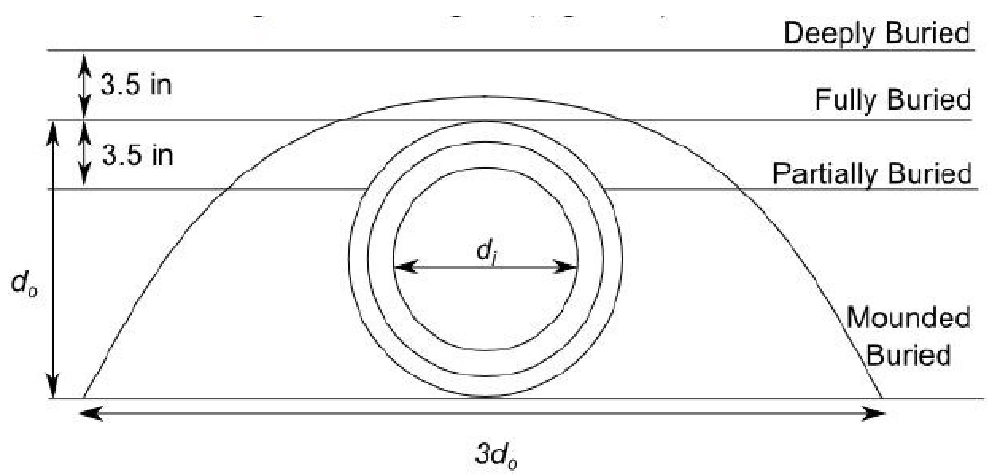


Figure 45. Definition of mounded-buried ducts

there is no reason to encapsulate ducts in California climates to prevent condensation. so Installing polyurethane foam in thicknesses greater than 2” greatly increases cost as well as risk of contaminating homes with uncatalyzed polymers and rendering them uninhabitable which has been the subject of several lawsuits.

At the request of CEC staff, Steve Winters and Associates submitted a memo entitled “Update of Apparent and Effective R-values for Buried and Encapsulated Ducts for Cellulose Insulation” (2018)*3, in which more detail of effective R-values is offered in a range of charts. Focusing on theR-values for ducts buried in blown fiberglass (Table 1 below), there is no detail of the variables that have resulted in the values stated, such as the depth of attic insulation for each diameter, which is presumed to be an inconsistent depth because the 16” diameter duct has lower btu loss than the 4” diameter duct which would in most field conditions be far more deeply buried. Such data should be qualified with definitions of key variables, such as the assumed R-value/inch of the insulation, the depth of the insulation and the height of the truss chords upon which the ducts rest. Since this memo appears to be an elaboration of the data offered in the 2013 NREL study*2, one would have to assume that the R-values for each of the ducts in the 2018 chart above references Figure 5. (pg. 7) of the 2013 paper shown below. However, in the world of scientific research, such a presumed reference would be a dangerous presumption without explicit clarification by the author, Steve Winter. Due to the lack of variable clarification, the basis and rationale for the partial, fully and deeply buried classifications merits questioning because of the inherent challenges of interpreting such tables when they are submitted without variable clarification, and the resulting inaccuracies which seem evident when applying heat loss equations and which result in effective duct R-values tables in the RACM that discourage more efficient duct design, and which discourage the known synergies accomplished through Rick Chitwood’s CEC supported research. Not only should these tables be re-examined, but deeply burying ducts on all types of ducted systems should be encouraged on retrofits to promote the most cost-effective energy savings for consumers and in support of truly beneficial electrification.

Table 1. Effective R-Values of Round Ducts Buried with Fiberglass

	R-4.2 Ducts			R-6 Ducts			R-8 Ducts		
Burial Level	Partially	Fully	Deeply	Partially	Fully	Deeply	Partially	Fully	Deeply
4-in. Diameter	5.6	8.4	14.3	7.1	9.9	15.2	8.5	11.2	16.1
6-in. Diameter	6.9	10.4	17.8	8.7	12.2	19.0	9.3	13.9	20.1
8-in. Diameter	8.1	12.0	20.7	10.2	14.1	22.1	12.3	16.2	23.5
10-in. Diameter	9.0	13.4	23.1	11.4	15.8	24.7	13.7	18.1	26.3
12-in. Diameter	9.9	14.7	25.2	12.5	17.2	27.0	15.0	19.7	28.8
14-in. Diameter	10.7	15.8	27.1	13.4	18.5	29.0	16.2	21.2	31.1
16-in. Diameter	11.5.	16.8	28.9	14.3	19.8	31.0	17.3	22.6	33.1

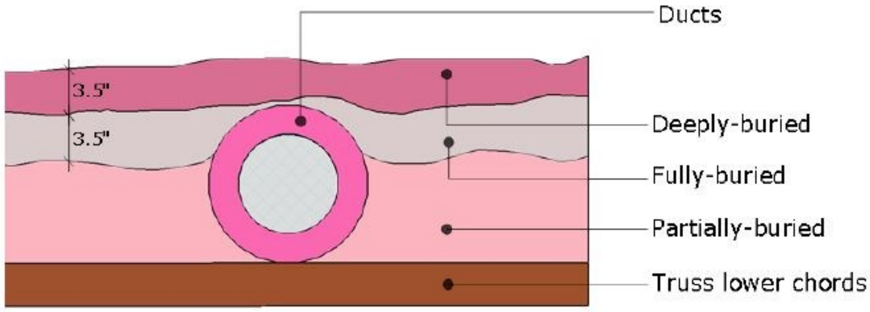


Figure 5. Categorization of duct insulation levels by burial class

From this discussion it is apparent that despite all of the attention to modeling detail in both the Griffith and Winter research, both approaches adopt simplification practices that embrace inaccuracies and blur the detail in ways that are detrimental to overall duct design. Neither study employed methods to measure duct efficiency in the field. Both studies reference ASHRAE Standard 152 which uses a calculation to determine or estimate the BTUs delivered at the supply registers to assess “delivery effectiveness” given climate, duct design and site variables. However, such estimates of delivery effectiveness can be accurately measured using NCI’s Heat-Max and Cool-Max method of measuring flow and delta-T between the supply plenum and the grills to determine actual BTUs delivered at each grill and overall duct losses given field conditions. Both of these research efforts missed the opportunity to employ such methods to confirm the accuracy of their modeling projections. It would benefit the CEC to incorporate such data acquisition into their ongoing field testing. There is no reason to adopt data from third party researchers without some field verification.

So why is accuracy of the effective duct value tables so significant? Rick Chitwood, one of the pioneering researchers to whom the 2004 Griffith-Zuluaga study makes reference in their introduction, has demonstrated the ability to optimize ducted heat pump installation by eliminating trunk and branch design altogether, and using only 5” to 8” ducts that all “home run” directly to the supply plenum. The subject of the comments originally submitted to the CASE Team and CEC staff (below) was to make an argument for why this “new-school” approach to ducted system design should be applied to all ducted systems, both single stage and variable capacity because it is extremely cost effective, and promotes a more beneficial electrification of heating systems, higher energy savings, ROIs, improved indoor air quality and lower HVAC peak loads on the grid, and much lower lifecycle costs when system and grid-impacts are fully considered. Because the current RACM tables for effective duct R-values embody assumptions about trunk and branch design, they discourage this innovative “new-school” approach which has significant benefits for residents, EE program managers, and grid managers.

> ***Chitwood’s Method calls for a range of cost-effective measures that minimize duct and fan losses while improving IAQ and can allow a capacity to area ratio of 1-ton/1000sf instead of the traditional 1-ton/400sf. If such system design were to become standard, there would be societal benefits to the tune of billions in energy savings and avoided grid infrastructure and battery storage costs. This approach should not be discounted based on prior inaccurate research.***

The table R-value simplification encourages old-school thinking and will lead to higher projected energy savings than will be realized or actually measured in the field. The inaccuracy is dangerous precisely because heat pumps with trunk and branch duct design, whether single stage or variable capacity, are more likely to experience lower energy savings in the field than predicted.

Another significant omission is the elimination of 2x6 framing which is simply disregarded as too high above drywall to allow deeply buried ducts, which is definitely not the case for smaller duct diameters. So many older homes have “cut and stack” roof framing that uses 2x6 rafters, and it is a regrettable omission which again discounts the real energy savings potential of deeply buring ducts on these older homes. Given the low incremental cost on new construction for R-50 and R-60 insulation, ($400 to $800 respectively on the average 1600sf home), consideration should also be given to encouraging these high value measures which improve envelope and duct efficiencies simultaneously.

In summary, the ACM R-value tables are in need of revision, precisely because they will exacerbate installation problems, lead to customer complaints about comfort and efficiency, lead to inaccurate energy savings estimates that are required for rebate programs, and worst of all, will discourage the market from embracing ducted HP systems and slow the market transformation that is needed to meet the State’s 2030 and 2050 climate mitigation goals.

Please see the original analysis submitted on March 24, 2020 on the following pages.

Text of the Previous Comment Submitted to the CASE Team and Mr. Payam Bozorgchami:

Mitsubishi Electric Comments VCHP Duct Losses, Optimized Installation and Unfactored Variables.

Submitted by Bruce Severance, Regulatory Compliance Engineer, March 24, 2020, in support of broader use of the Chitwood Method of ducted heat pump integration and optimization:

Concerns About Unfactored Variables in the WCEC Research

We commend the insights and science in the WCEC research and the efforts of CEC staff to use such research to educate best practices and improved HVAC installation quality. However, there are three areas of concern with unfactored variables in this study: 1) The study did not factor increased efficiency of VCHP systems due to lower cycling losses; 2) The studies compared ducts in vented attics that were not deeply buried to ducts in conditioned space and excluded deeply buried scenarios; and 3) There were no attic temperature controls by using either solar-powered fans or other means to reduce attic temperatures in summer and increase temperatures in winter. Cycling losses are significant because every time the equipment cycles on and off it takes time to get up to temperature, and btus are lost with each cycle. Research indicates that these losses can amount to 15% to 18% while motor losses due to pulse-width modulation controls are insignificant, in the range of 1% to 3% depending upon motor speed and load.*[1] Attic temperatures and the effective R-value of deeply buried ducts are key variables in the heat loss equation, and actual btu losses can be easily predicted and verified in the field based on more optimum attic conditions.

That such variables are accurately factored is critical. The vast majority of residential heat pump installs that will happen over the next thirty years will be "retrofit" projects, upgrades to existing homes, and where these are concerned, central heat pump systems that make use of some of the existing ducts, and which relocate ducts to attics rather than repairing leaking ducts in wall and floor assemblies will invariably be the most common and cost effective solution. Deeply burying ducts in blown attic insulation is cost effective on all systems, not only VCHPs, and higher attic insulation values provides double duty: reduced duct losses and reduced losses through the ceiling.

Residents invariably prefer NOT to have walls opened or drop ceilings added while they occupy the space, and doing so is in most cases a less cost effective solution. Electrification of the residential market as a whole, already has many barriers, and if plaster dust in the living space becomes a prerequisite for electrification to happen, it will not happen. Similarly, if ducts in conditioned space becomes the norm in new construction, all ducts concealed in wall and floor assemblies should be metal, not flex, with 2% duct leakage, to avoid continuation of the current problems with repairing ducts in such concealed and inaccessible spaces. Recommendations or compliance credit incentive to install ducts in conditioned space for retrofits or new construction should not create future duct access and repair problems that will likely degrade system efficiencies after the first 20 to 30 years of use. Such misdirected compliance credit would create lost value to residents, and a second wave of required repairs that would be far less expensive if ducts are installed where they are serviceable.

Avoided Cycling Losses Not Factored

The CEC's landmark field tests of VCHP equipment, the CVRH studies which have been conducted over the last five years, conclude that VCHP's are 12% to 18% more efficient than the single speed reference systems against which VCHP systems were compared. This performance increase was averaged over a range of products from three or four manufacturers over a period of years in both heating and cooling, and was the research team's conclusion even after a number of variables in the study put VCHPs at a disadvantage. It is important to note that most of the test scenarios, except some in the first year of the study, were conducted with ducts and air-handlers fully in conditioned space, so the performance increase is a clear indication of performance gains achieved by reducing cycling losses. However, the research also pointed to potential losses from continuously operating fans and compressors that do not fully cycle off during low-load conditions, and the importance of control software optimizing performance under high, partial, or low-load conditions. Although the CVRH research focused on low-static and ductless systems and for unknown reasons did not include research on mid or high static VCHP systems, the relevance of the avoided cycling losses is plainly evident. If the CASE Team uses the WCEC research to derate VCHP systems for duct losses, it should also consider both the common variables that reduce these losses as well as the cycling efficiency benefits of central VCHP systems.

WCEC Duct Losses Were Not Measured With Deeply Buried Ducts

It is true that duct losses will increase if flow velocities within the ducts are slower, which allows the heat transfer through the duct wall to reduce the heat or coolness delivered at the grills (delivered btus), however, this effect is dwarfed by other variables that are excluded from the

WCEC analysis. The relevance of Rick Chitwood's field research and system optimization methods cannot be overstated. The so-called Chitwood Method includes the following:

New School HVAC Design Principles:

- Run ducts short and throw air across the ceiling to outside walls with proper face velocities. This actually promotes better mixing.
- Strap ducts to the floor of the attic and bury them in blown insulation.
- Size systems at 800-1000sf/ton and use WrightSoft or Elite for duct design.
- Every drop is a home run with dampers at plenum. (No trunk and branch).
- Don't run ducts in crawlspaces if there is mold, rodents or access issues. Minimize runs through crawl space if you can deeply bury in attic.
- Right-sizing everything and aiming for 0-3% duct leakage saves the client money improves air quality, and minimizes particulate infiltration.
- MERV 13 filtration with larger and deeper (2") filter grill returns provides better IAQ while lowering static pressure, and improving efficiency.
- Measure & verify everything before HERS. Crews test their own work.

(Key points of CHITWOOD METHOD)

Whereas old school HVAC installers will insist that grills must be located near windows and exterior walls for comfort and mixing, it turns out that IR camera imaging indicates that "short ducting" by located grills near interior walls and throwing the air 12 to 18 feet toward the outside walls achieves better mixing. Windows are better performing than they were in the 1970's when these "old-school" methods and rules of thumb were developed, and today, comfort is not improved using these methods. Instead of old-school trunk and branch duct design, parallel short ducting, like parallel plumbing, achieves better performance but for different reasons: 1) If every grill has a 5" to 8" duct that "home runs" back to the supply plenum, ducts can be more deeply buried in insulation, greatly increasing the effective R-value of the ducts and reducing duct losses; 2) The elimination of wyes reduces turbulence and static pressure in the system; 3) Every grill having a "home run" to the supply plenum allows all of the system dampers to be located at the supply plenum starting collars; 4) Proper room by room load calculations allows all ducts to be sized correctly so the dampers at the supply are mostly open and used only for fine tuning temperature balancing between rooms; 5) Short duct design with grills located as close to the air handler as possible further reduces losses through the duct wall by as much as 50%; 6) Sufficient attic venting, and thermostatically controlled solar attic fans that operate mainly when air conditioning is running can significantly reduce attic temperatures in the summer and further reduce duct losses.

The following example scenarios are offered to illustrate how variables such as duct length, diameter, and effective R-value impact duct losses when they are plugged into the heat loss equation. Typical existing conditions in pre-1999 homes are also included because they help illustrate the improvement that optimized HVAC installation can achieve even in older homes with the constraints that retrofit work will allow:

Typical Old School – Doing the Math on Duct Losses

<u>EXAMPLE 1</u>: Typical Existing Conditions on Furnace Replacements:
Assuming 2100sf single-family dwelling, 40kbtu shell load, oversized 80kbtu furnace with 4-ton split AC system, 30% duct leakage, R-4.2 ducts hung at top of attic with trunk and branch duct design and no duct replacement:

Assumptions: temperature at top of attic in summer 120-140° F., 30° to 40 °F in winter. Supply is 58° F. in summer, 120° F. in winter. Total supply duct area is approximately 217 sf:

- 25’ of 10” supply trunk ducts, A=65sf
- 30’ of 8” supply duct, A=63sf
- 40’ of 6” supply duct, A=63sf
- 20’ or 5” supply duct, A =26sf

Heat Loss Equation (summer):
$Q(btuh) = A \times \Delta T / R$
$Q = 217 \times 72° / R\text{-}4.2 = 3720$btuh
(assumes ΔT of 72°)

Assuming most duct leakage is on the supply side, 30% x 80kbtu= 24kbtu plus duct wall losses of 3700btuh. <u>Supply side losses are over 27,000 btuh</u>.

Note: Oversized furnace relative to ducts raises static pressures, increasing duct leakage which is not included in this calc. Excludes return losses which will typically average 1000-1500btuh depending upon design and duct wall area.

Typically, existing furnaces are oversized for the total load of the home (btus required) to maintain temperature. It is not unusual at all to find 80,000 btu furnaces in 1200sf homes that would not require a system with more than half the capacity. From these estimated duct losses it becomes immediately evident that duct leakage is the more significant variable than losses through the duct insulation.

When considering retrofits involving a heat pump install performed to current standards, average existing duct leakage in California is 30%, but code requires leak reduction to 15% duct leakage to outside. If system sizing follows “old-school” practices rather than room by room load calculations using an accurate software program such as WrightSoft, HVAC contractors will frequently oversize systems to “err on the side of caution”. In reality, the additional capacity allows them to accommodate the very high leakage rate allowed by the code for heat pump and furnace replacements. The system needs to be oversized by 9kbtu just to cover the leakage losses. An additional 1800 btuh is required to cover losses through the duct wall even with R-8 duct insulation:

Typical Old School – Doing the Math on Duct Losses

<u>EXAMPLE 2</u>: Typical HP Retrofit: Assuming 2100sf single-family home, 40kbtu shell load, oversized 60kbtu heat pump with (new 5-ton ducted unit), 15% duct leakage, R-8 ducts hung at top of attic with trunk and branch duct design:

Assumptions: temperature at top of attic in summer 120-140° F., 30° to 40 °F. attic temperature in winter. Supply is 58° F. in summer, 115° F. in winter. Total duct wall area approximately 217 sf:

- 25' of 10" supply trunk ducts, A=65sf
- 30' of 8" supply duct, A=63sf
- 40' of 6" supply duct, A=63sf
- 20' or 5" supply duct, A =26sf

Heat Loss Equation (summer):
Q(btuh) = A x ΔT / R
Q = 217 x 72° /R-8 =1817btuh
(assumes ΔT of 72°)

Assuming most duct leakage is on the supply side, 15% x 60kbtu= 9kbtu plus duct wall losses (1800btu), <u>Supply side losses are about 11,000 btuh</u>.

Note: Excludes return losses which will typically average 1000-1500btuh depending upon design and duct wall area.

But both of these examples assume old-school duct design standards: trunk and branch design, long duct runs with grills near windows and exterior walls and ducts are hung from the attic ceiling where temperatures are generally 10 degrees F. higher than the attic floor. The math radically changes when a few key variables are changed: 1) Cut the duct wall area by 40% to 50%; 2) Increase the effective duct insulation by deeply burying it in blown insulation; and 3) Lower attic temperatures in summer by 10 to 20 degrees F. by operating temperature controlled solar attic fans and increasing attic ventilation to meet the 1sf/150sf code requirement. It is particularly cost effective to do all three on new construction, whereas moving all existing grill locations is not always cost effective on retrofit projects, but can save installation time and significant amounts of energy if register boots are located close to the eaves and low-slope rooflines inhibit easy access and a hot roof deck is in close proximity to duct location causing high heat transfer:

New School – Doing the Math on Duct Losses

<u>RETROFIT EXAMPLE</u>: Assuming 2100sf single-family dwelling, 35kbtu shell load, has right-sized 2.5-ton split HP ducted system, 3% duct leakage, R-8 ducts strapped to floor of attic with short duct design, parallel ducting design, deeply buried in blown insulation raises average duct R-value to R-20, air handler wrapped in R-8 if in attic:

Assumptions: temperature at top of attic in summer 120-140° F., 30° to 40° F. in winter. Supply is 58° F. in summer, 115° F. in winter. Total duct area is approximately 126sf:

- 20' of 7" supply duct, A = 37sf
- 40' of 6" supply duct, A = 63sf
- 15' of 5" supply duct, A =40sf

(Total supply duct area = 126sf, R=20)

Heat Loss Equation (summer):
Q(btuh) = A x ΔT / R
Q = 126 x 72° /R-20= 454 btuh

Assuming most duct leakage is on the supply side, 3% leakage, losses are 1260 btu plus duct wall losses at 432btu. <u>Supply losses are about 1700 btuh</u>.

Note: Excludes return losses which will typically average 1000-1500btuh depending upon design and duct wall area.

The cost of moving each register grill is about 1.5 hours in labor or $150 each, and most 3 bedroom homes have about 5 to 6 boots ($750-900). If boots are moved, it is not difficult to cut the duct wall surface area in half, thereby cutting duct heat transmission losses in half, and increasing effective duct R-value to R-20 by deeply burying ducts in R-60 insulation doubles efficiency again. However, the biggest gains result from full duct replacement so all the ducting can be sized to meet the btu requirements of each room in the house and meet or exceed the current 5% leakage standard. In the above best case scenario, 3% duct leakage is assumed, because this is fairly easily achieved on a retrofit wherein all ducting is accessible and all ducting is replaced using mastic on all the metal fittings prior to slipping flex onto the collars and zip-tying to hold it in place until it can be triple-wrapped with UL181 compliant tape. Of course, low-leakage air handler cabinets are required to meet such a tight leakage target, but the result is a drop in total duct losses that are only 16% of today's common practice (Example 2). The total cost to reduce duct losses in this way adds $800 for moving boots but saves $500 in duct material and installation costs (easier install). If an attic is blown with R-38 fiberglass, the cost is approximately $.95/sf to $1.10/sf, but increasing that insulation to R-60 costs only an additional $.45 to $.55/sf, and the increased system efficiency has a high ROI. The $1000 cost premium for a 2100sf home may pay for itself in the first cooling season.

The best case scenario for 2100sf new construction would be a VCHP system using extremely short ducts, a single mid-static compact air handler over the hall soffit with ducts in conditioned space, all metal ducts with near zero duct leakage and near zero duct losses. A mid-static air handler would be capable of servicing three bedrooms and a great room from the same soffit. However, if two zones are preferred, it is far more cost effective and practical to add a second mini-split system with either wall or a ceiling cassette units for the great room, dining and kitchen areas. It is not necessary to conditioned bathrooms, and if bath fans are operated by humidistats to control moisture at the source, it is preferable not to add grills in these rooms, and consider direct wall heaters with 15 minute timers to prevent the central system heat from being vented out by moisture control systems.

Not every builder will go to such lengths, and many if not all production builders are counting every penny that goes into a new home to maximize their margins. Creating drop ceilings to run all ducts in conditioned space can easily add $1000 to the cost of a home, and using metal ducts to eliminate concerns about future duct access and repairs will add another $500 to $1000. The most cost effective solution is to run ducts in the attic, use flex in all accessible areas, and shoot for low leakage rates and high insulation values as illustrated in the example below:

New School – Doing the Math on Duct Losses

NEW CONSTRUCTION EXAMPLE: Assuming 2100sf single-family home, 22kbtu shell load, has right-sized 2-ton split HP ducted system, 3% duct leakage, R-8 ducts strapped to floor of attic with short duct design, deeply buried in blown insulation raises average duct R-value to R-20, air handler wrapped in R-8 if in attic. Attic temperatures controlled using solar attic fans to reduce delta-T and duct losses:

Assumptions: temperature at top of attic in summer 110-120° F., 30° to 40° F. in winter. Supply is 58° F. in summer, 115° F. in winter. Total duct area is approximately 126sf:

- 20' of 7" supply duct, A = 37sf
- 40' of 6" supply duct, A = 63sf
- 20' of 5" supply duct, A =26sf

(Total supply duct area = 126sf, R=20)

Heat Loss Equation (summer):
Q(btuh) = A x ΔT / R
Q = 126 x 52° /R-20= 327 btuh

Assuming most duct leakage is on the supply side, 3% leakage losses are 720 btuh plus duct wall losses at 330btu. Supply losses are about 1050 btuh.

Note: Excludes return losses which will typically average 1000-1500btuh depending upon design and duct wall area.

To make such comparisons fair, we must consider what the current 2019 code requires and whether the above scenario represents a substantial improvement over the current standard. Although CBECC allows shorter ducts that are deeply buried in insulation to be modeled, the residential ACM and compliance manuals do not encourage parallel duct design rather than trunk and branch, and there is little to inform architects and HVAC contractors that duct losses can be cut by 66% below current standard by using these methods while *reducing* installation costs on new construction. In short the additional $.50/sf additional cost for R-60 insulation is offset by reduced material and labor costs for using short-duct design, whether that is done with a single speed central system or any variety of VCHP.

Mid-Length Ducts That Aren't Buried – Doing the Math

NEW CONSTRUCTION EXAMPLE (to 2019 Code): Assuming 2100sf single-family home, 22kbtu shell load, has slightly over-sized 2.5-ton split HP ducted system, 5% duct leakage, R-8 ducts strapped to ceiling of attic with longer parallel duct design, air handler wrapped in R-8 if in attic:

Assumptions: temperature at top of attic in summer 120-140° F., 30° to 40° F. in winter. Supply is 58° F. in summer, 115° F. in winter. Total duct area is approximately 160sf:

- 30' of 8" supply duct, A = 63sf
- 45' of 6" supply duct, A = 71sf
- 30' of 5" supply duct, A =26sf

(Total supply duct area = 160sf, R=20)

Heat Loss Equation (summer):
Q(btuh) = A x ΔT / R
Q = 160 x 72° /R-8= 1440 btuh

Assuming most duct leakage is on the supply side, 5% leakage, losses are 2100 btuh plus duct wall losses at 1440btu. Total losses are about 3500 btuh.

Note: Excludes return losses which will typically average 1000-1500 btuh depending upon design and duct wall area.

Duct losses can be cut to a fraction of current standard without an increase in initial system installation cost. If it's cheaper and saves money, why wouldn't this be part of the code for new construction? The only answer is that there seems to be a resistance to prescribing any specific method of reaching the required compliance credit whether EDR or TDV, and the designer's choice is given precedent. Even so, designers and contractors should be made aware of the math and methods that optimize system efficiency.

The exercise of looking at duct loss scenarios is relevant to a discussion about penalizing VCHP systems because of increased duct losses, because it is clear that there are viable methods to eliminate any of those losses through the use of the Chitwood Method, while the benefits of avoided cycling losses remain, and this can be achieved without requiring ducts in conditioned space (DICS).

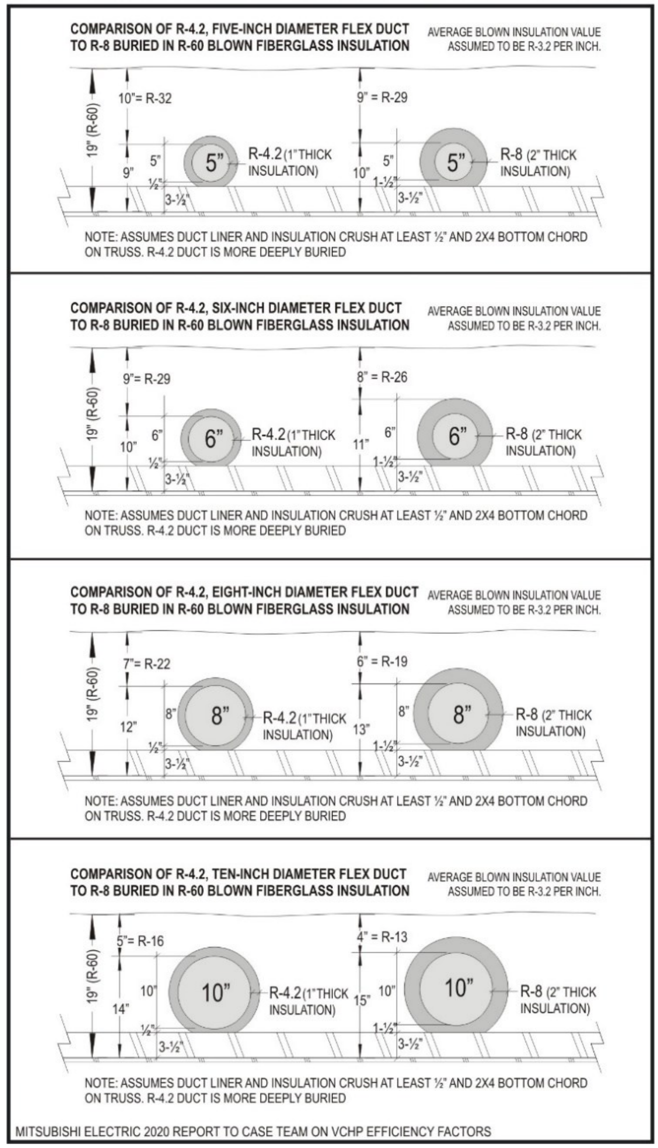
Why not DICS?

The argument is frequently made that ducts in conditioned space is optimal and there is little argument against this premise when it stands alone. However, there is always more to the picture. There are cost factors, as was mentioned before, but most importantly, and this is important, the code doesn't require that all ducts in conditioned space be metal ducts, and it makes no allowance for access to ducts in conditioned space for future duct repairs. Flex ducts and flex to metal duct joints will degrade and leak in time, and serviceability and the cost of opening drywall surfaces to make necessary repairs, even if that is 20 to 30 years down the road, is a significant lifecycle cost to the resident. The production builder will have retired by then, and only the most conscientious will consider it their obligation to consider such distant lifecycle/ reparability issues. Requiring DICS is like a time bomb for the homeowner, because flex duct and joints will fail, and there is little remedy short of incurring thousands in additional cost not to mention the inconvenience and downright pain of living in a home where drywall repairs are covering every surface and possession with dust. If ducts concealed in wall and floor assemblies are in need of repair, more often than not it is either too expensive, or too inconvenient for the homeowner to consider. Efficiency is irretrievably lost.

Why Not Unvented Attics?

Vapor drive happens. In California's dry climate, vapor drive moves from more humid interiors toward the dryer outside air. In numerous experiments with unvented attics, it has been found that moisture migrates upward in a home toward the peak of the roof and it can accumulate there, causing moisture damage to the plywood or OSB deck material and rafters. Unless there is an automated moisture control system in the attic that is operated by humidistats, the liability of such potential damage to the structure is not worth the cost of the experiment. Because California climates do not have sufficient humidity to build up condensation on ducting in the attic as is the case on some southern states, vented attics are both cheaper and preferable from a resiliency perspective, fire hazard areas being an important exception.

EFFECTIVE R-VALUE OF DUCTS BURIED IN R-60 BLOWN FIBERGLASS INSULATION



Concerns about the Effective Duct R-value Charts in the Res ACM Manual

It appears from careful analysis of the CEC's "Effective Duct R-Value" charts found in the Residential ACM Reference Manual (pages 44-45) that the effective values are incorrect, and this merits consideration and review by staff. Many of the Effective R-values appear to be off by the thickness of rafters and truss bottom cords, and it may be that there was an assumption made that ducts would rest on the drywall ceiling, when this is rarely the case. Because rafters are often oriented across the short axis of the building, while rooms are oriented along the long axis, duct runs that are installed at the so-called "floor" of the attic are actually elevated above the drywall ceiling surface by the thickness of the framing, usually 2x4 trusses, but frequently in older homes 2x6 "cut and stack" framing is used. Also, it appears that the R-values 'plateau' in a manner that is not consistent with real world applications, and this is a cause of further inaccuracies in the chart. Please note on the R-4.2 Effective Duct R-value chart below, that under R-60 fiberglass, an R-22 value used below across a range of duct sizes from 4" diameter to 14” diameter, when in fact the R-value range when more precisely calculated is R-4 to R-35). If the intent is to create an average based on the assumption that a range of duct diameters will be used in a trunk and branch configuration, such an assumption discourages optimized “parallel duct design” wherein smaller duct diameters are used and all ducts “home-run” to the supply plenum, so there are no larger diameter “trunks” that protrude from the surface of the insulation and there are no “wyes” in the system to increase turbulence and static pressure.

We have taken the time to show section drawings of a range of duct sizes in both R-4.2 and R-8 duct with a 2x4 bottom cord elevating the ducts, and accounting for the compressed thickness of the duct insulation which varies between ½” for R-4.2 and 1” to 1-½” for R-8. These diagrams illustrate the inaccuracies in the published 2019 Effective Duct R-value charts. All of the revised values that

Table 17: Buried Duct Effective R-Values: R-4.2 Ducts

	R-4.2 Insulated: Nominal Round Duct Diameter														
Attic Insulation	3"	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
	Effective Duct Insulation R-Value for Blown Fiberglass Insulation														
R-30	R-13	R-13 R-5	R-13 R-4	R-13 R-4	R-9	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-38 (12"/ 8" to cover)	R-22	R-22 R-13	R-22 R-10	R-13 R-6	R-13 R-4	R-13	R-13	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-40 (12-1/2"/ 8-1/2" to cover)	R-22	R-22 R-14	R-22 R-11	R-22 R-8	R-13 R-5	R-13 R-4	R-13	R-13	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-43 (13-1/2"/ 9-1/2" to cover)	R-22	R-22 R-17	R-22 R-14	R-22 R-11	R-22 R-10	R-13 R-9	R-13 R-7	R-13 R-4	R-9 R-4	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-49 (15-1/2"/11-1/2" to cover)	R-22	R-22 R-24	R-22 R-21	R-22 R-18	R-22 R-14	R-22 R-11	R-22 R-8	R-22 R-4	R-13 R-4	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2
R-60 (19"/15" to cover)	R-22	R-22 R-35	R-22 R-32	R-22 R-29	R-22 R-25	R-22 R-22	R-22 R-19	R-22 R-16	R-22 R-10	R-22 R-4	R-13 R-4	R-9	R-9	R-4.2	R-4.2
	Effective Duct Insulation R-Value for Blown Cellulose Insulation														
R-30	R-15	R-9	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-38	R-15	R-15	R-15	R-9	R-9	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-40	R-29	R-15	R-15	R-15	R-9	R-9	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-43 (12"/ 7" to cover)	R-29	R-15 R-10.5	R-15 R-7	R-15 R-4	R-15 R-4	R-9 R-4	R-9 R-4	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-49 (14"/10" to cover)	R-29	R-29 R-21	R-29 R-17	R-15 R-14	R-15 R-11	R-15 R-7	R-15 R-4	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-60 (17"/13" to cover)	R-29	R-29 R-32	R-29 R-29	R-29 R-25	R-29 R-21	R-29 R-13	R-15 R-10	R-15 R-4	R-15 R-4	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2

Source: California Energy Commission

NOTES REGARDING MITSUBISHI ELECTRIC’S ASSESSMENT OF THE ABOVE EFFECTIVE R-VALUE CHART:

NOTE: Suggested corrections to R-value take into account the height of the truss bottom cord or rafter heights, which appears not to have been factored in the above “Effective Duct Insulation” charts included in the 2019 residential ACM Manual. All of the recommended R-values generated by Mitsubishi Electric appear below those that appear in the original CEC chart. All recommended R-values appearing in white are taken from the accompanying duct section diagrams that show duct coverage given duct diameter, duct wall R-value and insulation depth. Only the R-4.2 and R-8 duct charts are shown. The R-6 duct chart is omitted because it was not deemed necessary to illustrate the relationships. The 2019 version of the charts create plateaus of R-value that do not correlate with actual installation conditions, keeping in mind that trusses and rafters usually run along the short axis of a building, while rooms are usually oriented along the long axis of a building, with the result that the majority of ducts in an attic rest on the rafters, and not on the drywall ceiling between rafters. A false assumption appears to have been made about this orientation or relationship in the process of generating these charts, because most values entered are off by the 4” thickness of the 2x4 bottom cord plus the crushed dimension of the duct lining insulation, estimated to be ½” to 1” thick.
ASSUMPTIONS: The overall insulation depths noted below the attic insulation R-values at the left of the chart are based on an average R-value per inch of R-3.5/inch for cellulose and R-3.2/inch for blown fiberglass. The “inches to cover” indicates the height of the insulation above the bottom cord after the 3-1/2” stud and the crushed dimension of the duct insulation are factored.
IMPORTANT NOTE: Since the rafter or bottom cord dimension directly effects the buried depth of the ducts, there should be separate charts for 2x6 cut and stack roof assemblies and 2x4 truss assemblies.

NOTE: The revised R-values in white and yellow were added by Mitsubishi Electric and assume blown fiberglass insulation R-values of R-3.2/inch and cellulose R-values of R-3.5/inch with moderate compression of flex ducts at the truss bottom chord. Similar inaccuracies appear if the Griffith-Zuluaga fiberglass R-value of R-2.5/inch are employed.

appear in white below the original CEC values on the charts are based on the section drawings and the assumptions listed on them. All of the values that appear in yellow are based on calculations from the clearances and "depth to cover" (the ducts) that have been added to the charts. Because it is less dense, and thus more deeply buries ducts, fiberglass insulation allows ducts up to 8" with sufficient coverage to reach R-20.

Table 15: Buried Duct Effective R-Values: R-8 Ducts

	R-8 Insulated: Nominal Round Duct Diameter														
Attic Insulation	3"	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
	Effective Duct Insulation R-Value for Blown Fiberglass Insulation														
R-30	R-18	R-13	R-13	R-13	R-13	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-38 (12"/ 7" to cover)	R-26	R-18	R-18	R-18	R-13	R-13	R-13	R-13	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-40 (12-1/2"/ 7-1/2" to cover)	R-26	R-26	R-18	R-18	R-18	R-13	R-13	R-13	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-43 (13-1/2"/ 8-1/2" to cover)	R-26	R-26 R-14	R-26 R-11	R-18 R-9	R-18	R-18 R-8	R-13	R-13	R-13	R-8	R-8	R-8	R-8	R-8	R-8
R-49 (15-1/2"/10-1/2" to cover)	R-26	R-26 R-22	R-26 R-18	R-26 R-14	R-26 R-11	R-18 R-10	R-18 R-8	R-18 R-8	R-13	R-13	R-8	R-8	R-8	R-8	R-8
R-60 (19"/14" to cover)	R-26	R-26 R-32	R-26 R-29	R-26 R-26	R-26 R-22	R-26 R-19	R-26 R-16	R-26 R-13	R-26 R-8	R-18	R-13	R-13	R-8	R-8	R-8
	Effective Duct Insulation R-Value for Blown Cellulose Insulation														
R-30	R-14	R-14	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-38	R-20	R-14	R-14	R-14	R-14	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-40	R-20	R-20	R-14	R-14	R-14	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-43 (12"/ 7" to cover)	R-20	R-20 R-9	R-20 R-8	R-14 R-8	R-14	R-14	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-49 (14"/9" to cover)	R-32	R-20 R-18	R-20 R-14	R-20 R-11	R-20 R-8	R-14 R-8	R-14	R-14	R-8	R-8	R-8	R-8	R-8	R-8	R-8
R-60 (17"/12" to cover)	R-32	R-32 R-28	R-32 R-24	R-32 R-21	R-20 R-18	R-20 R-14	R-20 R-11	R-20 R-8	R-14	R-8	R-8	R-8	R-8	R-8	R-8

Source: California Energy Commission

NOTES REGARDING MITSUBISHI ELECTRIC'S ASSESSMENT OF THE ABOVE EFFECTIVE R-VALUE CHART:

NOTE: Suggested corrections to R-value take into account the height of the truss bottom cord or rafter heights, which appears not to have been factored in the above "Effective Duct Insulation" charts included in the 2019 residential ACM Manual. All of the recommended R-values generated by Mitsubishi Electric appear below those that appear in the original CEC chart. All recommended R-values appearing in white are taken from the accompanying duct section diagrams that show duct coverage given duct diameter, duct wall R-value and insulation depth. Only the R-4.2 and R-8 duct charts are shown. The R-6 duct chart is omitted because it was not deemed necessary to illustrate the relationships. The 2019 version of the charts create plateaus of R-value that do not correlate with actual installation conditions, keeping in mind that trusses and rafters usually run along the short axis of a building, while rooms are usually oriented along the long axis of a building, with the result that the majority of ducts in an attic rest on the rafters, and not on the drywall ceiling between rafters. A false assumption appears to have been made about this orientation or relationship in the process of generating these charts, because most values entered are off by the 4" thickness of the 2x4 bottom cord plus the crushed dimension of the duct lining insulation, estimated to be ½" to 1" thick.
ASSUMPTIONS: The overall insulation depths noted below the attic insulation R-values at the left of the chart are based on an average R-value per inch of R-3.5/inch for cellulose and R-3.2/inch for blown fiberglass. The "inches to cover" indicates the height of the insulation above the bottom cord after the 3-1/2" stud and the crushed dimension of the duct insulation are factored.
IMPORTANT NOTE: Since the rafter or bottom cord dimension directly effects the buried depth of the ducts, there should be separate charts for 2x6 cut and stack roof assemblies and 2x4 truss assemblies.

Although R-4.2 ducts achieve higher effective R-values when buried because the duct they end up being more deeply buried, in parallel duct design, ducts often emerge from the insulation to connect with the supply plenum which is may be suspended from the ceiling in the attic just above the insulation level. If R-4.2 ducts were used, this would increase effective R-value, but only if the ducts are double-wrapped with FSK duct insulation where they are no longer buried. Otherwise, R-8 ducting would be preferable. Because all of the ducts "home-run" to the supply plenum in an optimized design, air-handlers are generally located in attics, but they can be located in conditioned space, in a hall closet with a longer supply plenums protruding above the ceiling into the attic, so the many ducts can be attached to starting collars above the ceiling. If such a configuration is used, the portion of the supply plenum that is exposed to attic temperatures should be double wrapped with FSK R-8 insulation to minimize losses. (See configuration diagrams in Appendix A.)

NOTE: The remaining duct section drawings can be found in Appendix B which show duct depth and effective R-values that correlate with the above data in white for both R-43 and R-49 attics.

Combining VCHP Systems with Duct Zoning Plenums is a Questionable Strategy

The suggestion that VCHP systems can be paired with duct zoning plenums was made during the CASE Team presentation, and we are concerned that this solves the static pressure problems associated with zoning plenums, but that it adds an unnecessary layer of system complexity when there are cheaper and more reliable solutions. Zoning plenums on the whole, have some reputation for reliability. Although they seem to solve the age-old problem of diverting airflow from unoccupied spaces to occupied spaces, they subsequently can reduce airflow through a single stage heat pump, thereby increasing static pressure and fan watt-draw and reducing critical airflow across the coil. In the case of furnace heat exchanger, the reduced airflow can cause overheating of the exchanger, which can lead to heat exchanger cracks and CO poisoning scenarios. Such failure modes may or may not be solved by combining zoning plenums with VCHP systems that can reduce fan speed to accommodate flow being diverted to only half the ducts in a home. However, it is not an elegant solution, and it offers no cost or reliability advantages over a multi-zone mini-split, which in its simplest form would employ a compact mid-static air handler to accommodate 2-4 bedrooms, and a wall or ceiling cassettes to cover the living room-great room areas. Again these configurations have been explored by CEC research staff and recommended by Rick Chitwood. Zoning plenums generally cost about $3k to install, and for about the same money, a 2-zone multi-split system can accomplish the same result with greater efficiency and reliability.

Conclusions and Concerns Compliance Credit Assignment

Mitsubishi Electric is concerned that the CASE Team has suggested that VCHP duct losses due to slower velocities and higher heat transfer in unvented attics renders them less efficient on the whole and supports re-insulation or increased insulation in attics at time of system replacement to optimize system sizing and provided the highest value and ROI to the resident or homeowner. Clearly, from the analysis above, duct leakage is a far more significant variable, and duct losses can be nearly eliminated by deeply burying ducts for any type of system, and further, the CSLB should consider attic improvements that reduce HVAC loads as within the scope of an HVAC contractor's license, because they directly impact the quality and performance of the system install. We are asking CEC Staff and CASE Teams to thoroughly consider the system configuration and design options that are most affordable, efficient and serviceable in the long run, and that the code, effective R-value tables, and CBECC specifically encourage the Chitwood optimization methods which are not broadly known or recognized among HVAC contractors. *Consideration, and preference should be given to installation methods that accommodate all potential future service requirements.* Specifically, if CBECC is going to assign higher compliance credit to ducts in conditioned space, it should also require that all ducts concealed in wall and floor assemblies be metal ducts wrapped in R-6 FSK and sealed with mastic to a maximum leakage rate of 2%, so that the resident is protected against costly and catastrophic duct failures that would eventually occur. The DICS condition should also be carefully compared to parallel duct design with higher than R-20 effective duct values, and CBECC compliance credit should be thoughtfully assigned in a manner that is proportional to the actual energy savings achieved by each of these configurations. The consequence of not assigning compliance credit fairly, is that it forces residents or home builders to adopt more expensive installation practices that may have negative long-term consequences and lower near term ROI.

We also ask that the CEC consider the reduced cycle losses of VCHPs which was not factored in the WCEC investigation. Granted, control software must be optimized across all models to avoid unnecessary fan losses as demonstrated in the CVRH research, VCHPs still achieve significant and measurable energy savings over single stage equipment. We do not want consumers and architects to be discouraged from specifying higher efficiency, and higher benefit products due to quirks in code interpretation and compliance credit assignment.

As a manufacturer of central ducted VCHP systems as well as mini-splits and multi-splits, Mitsubishi Electric realizes that many production homes as well as many retrofit projects will settle on central systems rather than mini-splits and multi-splits because of cost considerations. Not every project requires multiple zones, and residents are used to one thermostat controlling an entire home. Optimized system design and parallel duct design as well as ACCA approved duct design software now make it possible to balance rooms to within 2 degrees F. so that multiple zones are not necessary to achieve high levels of resident comfort and product satisfaction. Parallel duct design makes it possible to fine tune temperature balancing at the supply plenum, so the additional expense of multiple zones is not necessary, and central VCHP design is an appropriate and affordable solution for many if not most new production homes. In short, there is a strategy that makes VCHPs easy and affordable to install, with perfect balancing and optimized efficiency. Many of these system optimization methods are applicable to single stage equipment as well, and it is important that this is not only allowed by within the code, but also recognized as a preferred installation method with appropriate compliance credit assigned to parallel duct design within CBECC.

Unfortunately, the Chitwood Method and the advantages of parallel duct design does not seem to be clearly articulated or encouraged by current code or CBECC, and the effective R-value tables in the 2019 ACM actually discourage it by rating a 4" and a 14" duct similarly, despite their obvious R-value differences when they are buried ad differing depths. On a positive note, the functionality of the CBECC buried duct interface works well, and can accommodate parallel duct design if it were encouraged both by compliance credit and supporting documentation and training.

Parallel duct design with minimum R-20 effective R-values are more cost effective and serviceable than ducts in conditioned space (DICS) and it deserves to be recognized. We see full implementation of the Rick Chitwood's optimization methods, as well as a clear path for parallel duct design deeply buried in the attic to be far more cost effective. We are greatly concerned that the current CASE Team discussion about duct losses will lead to a requirement that VCHPs would be required to have ducts in conditioned space, or that the WCEC finding of increased duct losses due to reduced flow rates will be given undue importance relative to the many variables presented in this analysis.

Thank you for the opportunity to comment on this critical policy issue. Respectfully submitted,

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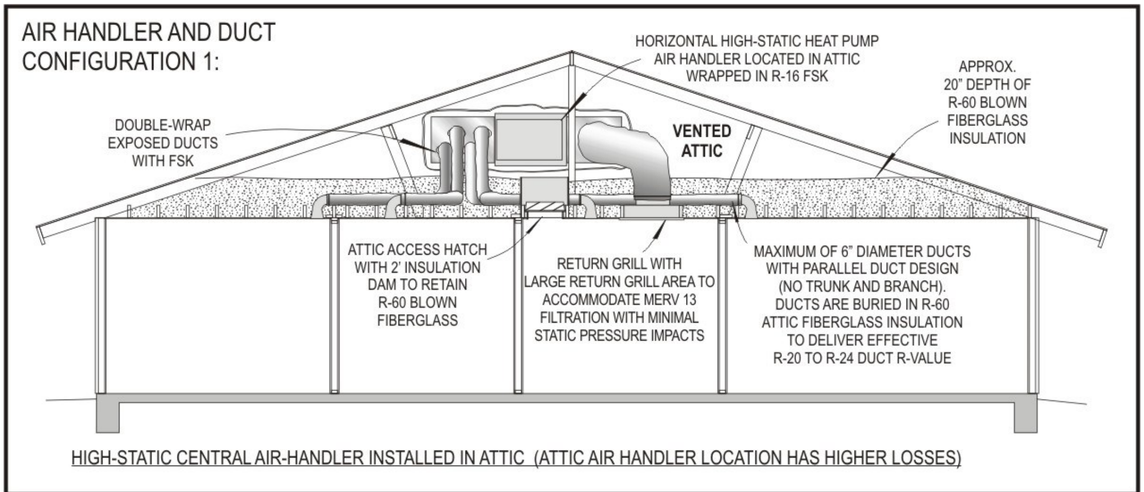
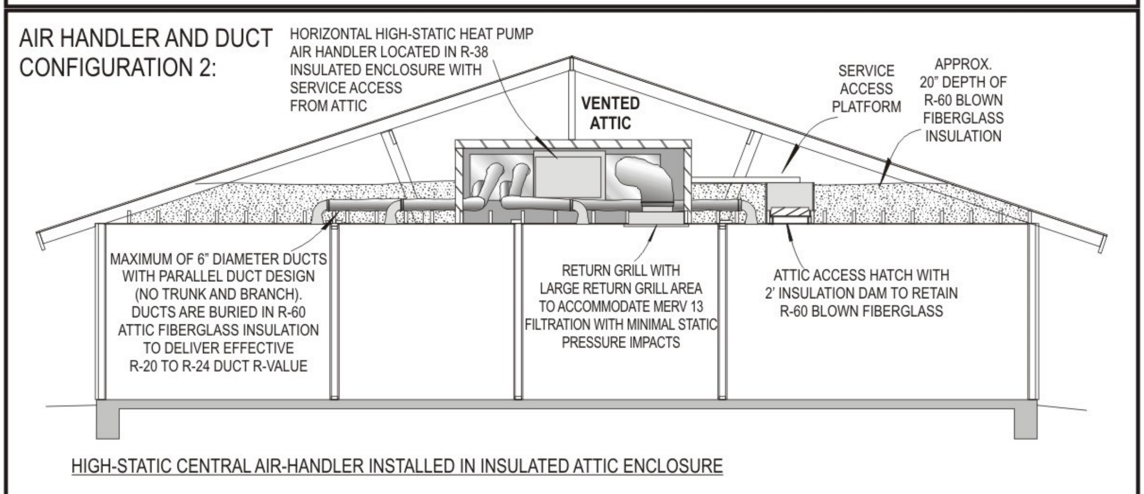
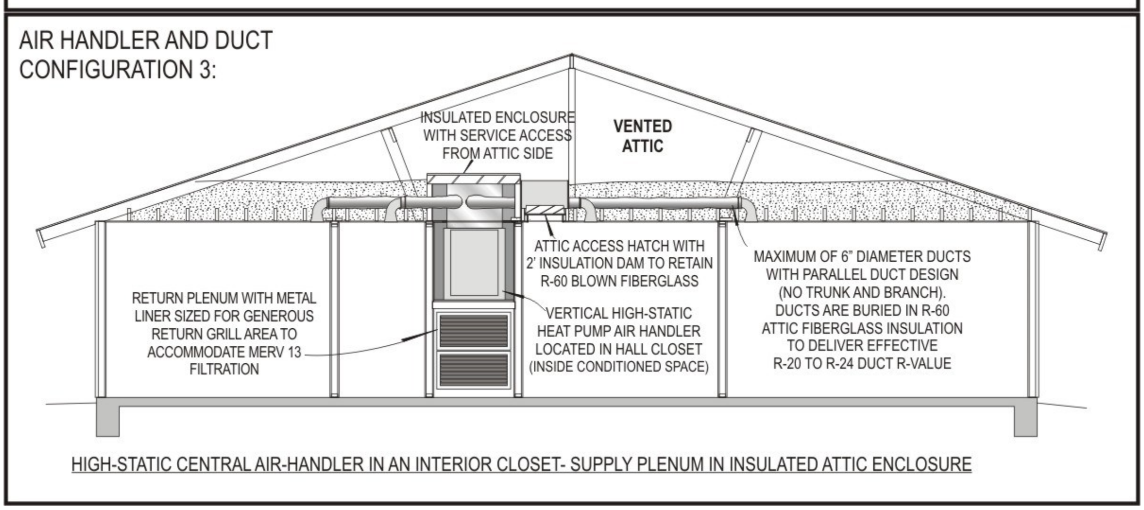
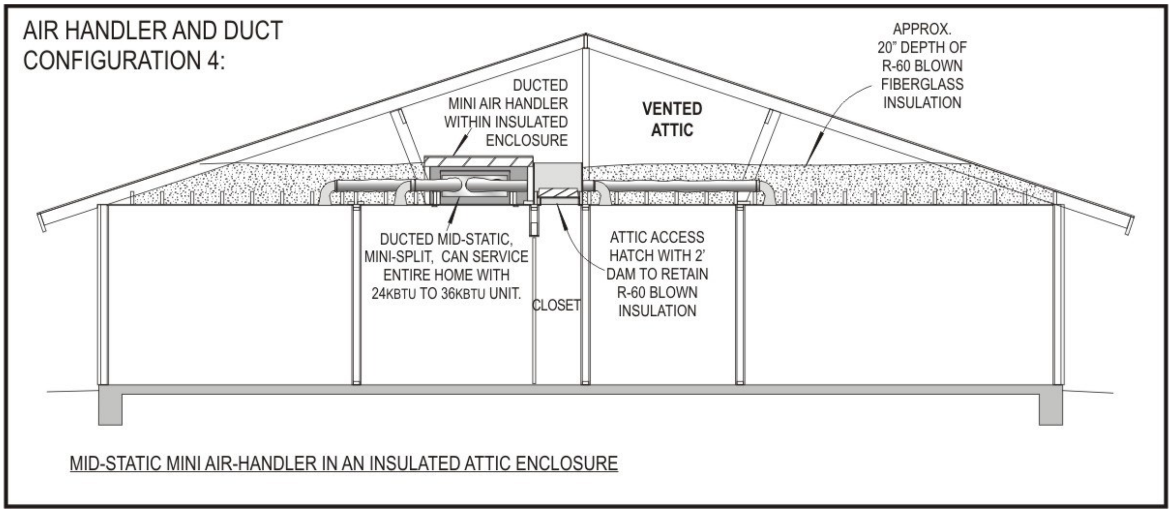
Appendix A: Configuration Drawings



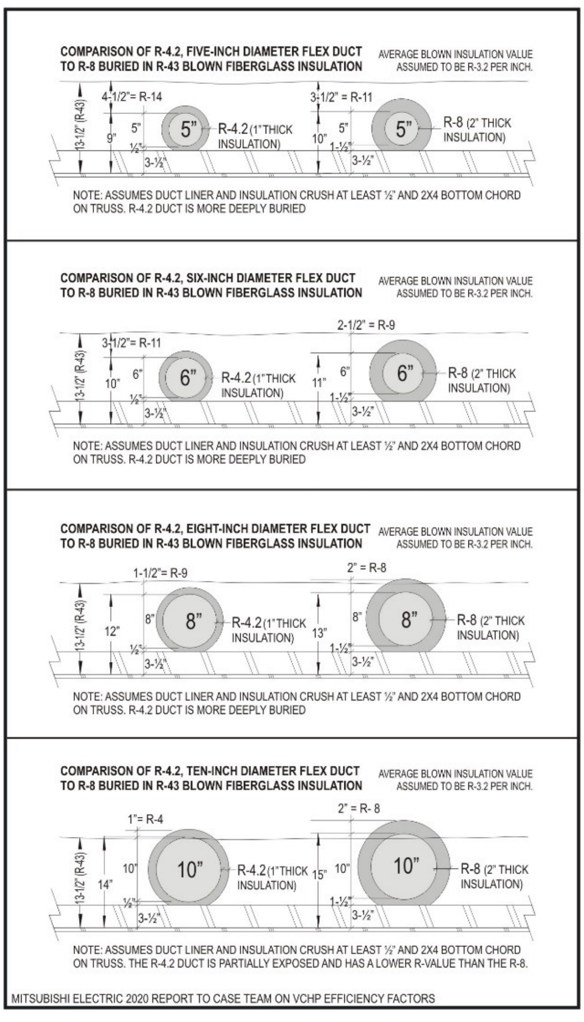




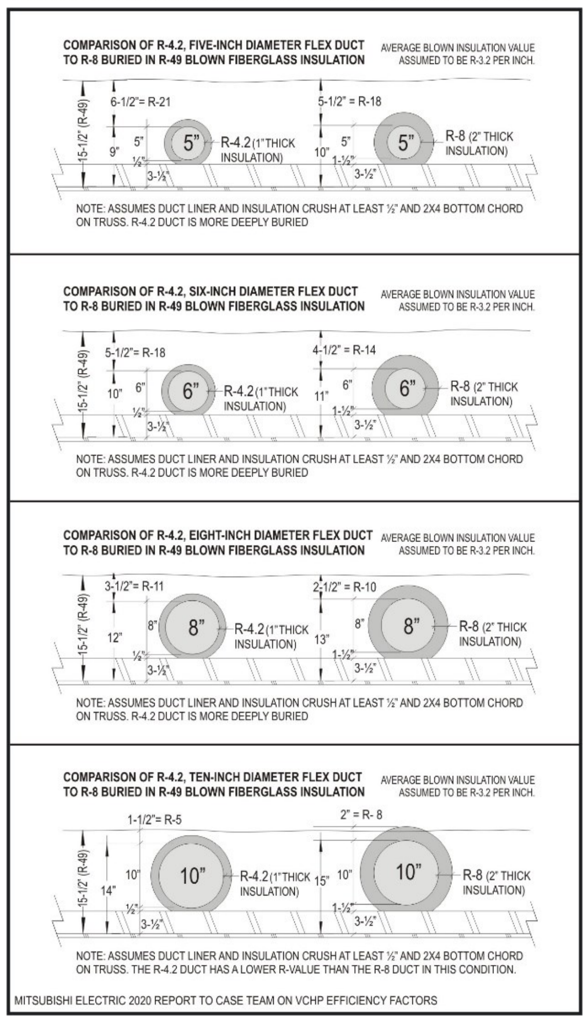


Appendix B: Duct Effective R-value Section Drawings

EFFECTIVE R-VALUE OF DUCTS BURIED IN R-43 BLOWN FIBERGLASS INSULATION



EFFECTIVE R-VALUE OF DUCTS BURIED IN R-49 BLOWN FIBERGLASS INSULATION



FOOTNOTES:

*1 An Analysis of the Effective R-Value for Insulation Buried Attic Ducts, *ASHRAE Transactions* (110:2); pp. 721–726, Griffiths, D.; Zuluaga, M. (2004), p. 725

*2 Reducing Thermal Losses and Gains With Buried and Encapsulated Ducts in Hot-Humid Climates, C. Shapiro, A. Magee, and W. Zoeller, S. Winter, DOE & NREL, Consortium for Advanced Residential Buildings, February 2013

*3 Update for Apparent and Effective R-values for Buried and Encapsulated Ducts for Cellulose Insulation, Memo to the CEC from Steve Winter and Associates, 2018.

*4 Performance Assessment of Variable Frequency Drives in Heating, Ventilation and Air-Conditioning Systems, ASHRAE, 2018, ISSN: 2374-4731.2018.1469947, by Gang Wang (U of Miami) and Li Song (U of Oklahoma).