HVAC Fuel Substitution Measure Research

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Presented by:
Bryan Boyce

Presented to:
Cal TF

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Research Drivers

- Space heating is a significant source of California's GHG emissions
- GHG Emissions can be reduced with fuel substitution

Existing Fuel Substitution Measures in eTRM

- Residential Ductless Heat Pumps
- Residential Central Heat Pumps
- Commercial Unitary Heat Pumps

Scope and Future Landscape

Scope of Research

- This research investigates a variety of electric space heating options that can be used in fuel substitution applications.
- Three main categories of electric space heating: heat pumps, heat recovery and electric resistance.

Key Findings

- “Partial fuel substitution” could allow the offloading but not decommissioning of the existing natural gas equipment.
- Grouping specific measures by efficiency and technology patterns allows estimation of source Btu and GHG emissions easy
- Thermal energy storage (TES)- a promising technology to pair with heat recovery. It will be critical in reducing peak heat pump capacity needs.
- Mechanical heat recovery (a compressor-based system) is a critical for commercial building fuel substitution. It should be paired with TES and/or ASHP.
- Energy penalty of electric resistance is minimal for a zone with very low heating loads.

HVAC Fuel Substitution

- Baseline space heating system using natural gas is replaced by electric-powered systems, such as
  - Heat pumps
  - Heat recovery (including building internal loads and TES) specifically in large commercial buildings
  - Electric resistance (in zones with limited space heating loads)- cost effective and eliminates high GWP refrigerants in the measure case.
- Caution must be exercised in designing
  - Right sized electric systems as opposed to “oversized” gas systems
  - Appropriate controls to avoid routine practices of gas systems involving overnight setback and morning warm-up periods
- Morning warmup can be extended over a longer period for all-electric without much of an energy penalty

Potential Innovative Opportunities

Energy Efficiency (EE) Measures

- EE can reduce building space heating loads
- EE measures include building envelope upgrades and HVAC controls upgrades; however, EE measures are not focus of this research

HVAC Controls Measures

- Addition of Direct Digital Control (DDC), programming sequences to comply with ASHRAE Guidelines 36 and bringing building controls to new construction requirements of Title 24
- Morning warmup period extended to longer duration to reduce the peak electric demand
- Distributed generation measures (e.g., solar PV, batteries) to offset potential winter morning electric demand

Residential

Residential HVAC Fuel Substitution Measures

R1: Combination Domestic Hot Water and Space Heating Heat Pumps

R2: 120V Heat Pumps

R3: Air-to-Water Heat Pumps (AWHP)

R4: Ground Source Heat Pumps (GSHP)

R5: Ductless Heat Pump (DHP)

R6: Central Ducted Heat Pump (CDHP)

R7: Electric Resistance (ER) Heating

R8: Dual Fuel Heat Pumps

Commercial HVAC Fuel Substitution Measures

C1 (Air Source Heat Pump): Air-to-air HP, Air-to-water HP and Air Source VRF HP without heat recovery

C2 (Mechanical Heat Recovery): Air source HR Chillers, Water source HR chillers, VFR with HR

C3 Water Source Heat Pumps): Water-to-air HPs, Water-to-water HPs, Water Source VRFs

C4 (Ground Source Heat pump) : Ground Source Heat Pumps (GSHP)

C5 (Thermal Energy Storage): TES

C6 Electric Resistance (ER): Electric Resistance (ER) Heating

C7 (Waste Fluid Heat Recovery): Exhaust air HR + Waste-Water HR

C8 Single Zone Wall-Mounted Equipment): Packaged Terminal HP (PTHP), Single Packaged Vertical HP (SPVHP)

Commercial HVAC Fuel Substitution Measures

C9 (ASHP+ Mech HR): CUHP +Mech HR, AWHP + Mech HR, VRF + Mech HR

C10 (ASHP + WSHP): Air Source HP, Water Source HP

C11 (ASHP + Mech HR + TES): Air Source HP, Mech HR, Thermal Energy Storage (TES)

C12 (ASHP + Waste Fluid HR): Air Source HP, Waste Fluid HR

C13 (Electric Resistance+ others): Electric Resistance bundled with additional measures (envelope improvement, HVAC controls upgrade, solar PV, battery)

C14 (ASHP + Mech HR + TES in exterior zones & ER in interior zones): ASHP + Mech HR + TES in exterior zones & ER in interior zones)

C15 (EE/DG Measures): Lower hot water supply temperature (HWST), DDC, Building envelop improvement, PV + storage, Solar thermal assisted water heating

R1: Combination Domestic Hot Water and Space Heating Heat Pumps

- “Multi-function heat pumps” provide space heating and water heating functionality using a domestic water tank as a thermal battery to provide space heating and cooling needs
- Benefits of thermal storage allows HP compressor to operate during warmer daytime, leading to
- higher efficiency and overlap with higher solar energy production (lower electrical rates).
- Disadvantages include-
  - lack of a standardized test method
  - existing performance ratings (UEF for water heating and HSPF2 for HPs) do not map well
- Energy Savings Estimate:
  - 79% space heating energy use reduction vs. a new code compliant furnace
  - 85% water heating energy use reduction vs. a new code compliant gas-fired water heater.
- Examples of Manufacturers
  - Harvest Thermal HarvestPod Duo
  - Villara Building Systems
  - Daikin Altherma
  - Panasonic Aquarea
  - Fujitsu Waterstage

R2: 120V Heat Pumps

- 120V, variable speed Window HPs offer both cooling and heating capabilities without the need for a potentially expensive panel upgrade
- Various ergonomic designs appearing in the market to fit in a window frame without extensive installation procedure, through-the-wall, and/or as portable air conditioners.
- They can be potential game-changer to address decarbonization of millions of gas-fired heating appliances or electric-resistance space-heaters in multi-family buildings across California
- 120V, single phase, 60Hz, 15 amp socket

		
Source: Gradient WHP	Source: Midea WHP	Source: Islandaire WHP (PTHP)

R3: Air to Water Heat Pumps (AWHPs)

- AWHPs can provide space heating, space cooling and domestic hot water with quiet operation down to -25°C
- Space heating through hydronic distribution (e.g., radiant floor, radiator, or baseboard water circulation systems).
- Energy savings up to 47% (ENERGY STAR 2019-20) with a seasonal Coefficient of Performance (COP) of 1.7 - 3.0.
- A very promising FS technology but not cost-effective vs. natural gas or air-to-air heat pump alternatives

		
Source: Midea AWHP	Source: Apollo 6 Ton AWHP	Source: Solstice AWHP
R32, Heating Capacity:15.5kW	R410A; Variable speed fan	EPA awarded Energy Star award to its model LAHP48

R4: Ground Source Heat Pumps (GSHPs)

- Uses temperature difference between the ambient air and the soil to provide heating and space cooling
- 4-types of heat exchanger
  - Horizontal heat exchangers (just below the ground surface)
  - Vertical (can go several hundred feet below the ground)
  - Pond/lake (immersed in pond water
  - Open-loop (Water is circulated through the heat exchangers).
- High installation costs due to rocky soil in California, pay back period from 5 to 10 years.
- A promising FS technology but not cost-effective vs. natural gas or air-to-air heat pump alternatives.

R5: Ductless Heat Pumps

- Ductless Heat Pumps, also known as mini-split systems, are one of the few HVAC FS measure packages in the eTRM (SWHC044)
- The indoor unit includes a fan and an evaporator coil, while the outdoor unit includes a compressor, condensing coil, and a fan.
- No ducts and hence no heat losses, however, long refrigerant lines result in high refrigerant volume.
- CPUC RACC should be properly leveraged to fully quantify the impact of adding low GWP refrigerant (such as R32) to the system as part of the measure.
- Measure package SWHC044 could be updated with new performance maps to reflect latest SEER2/EER2/HSPF2 ratings, and new offerings of inverter driven variable speed compressors

R6: Central Ducted Heat Pumps (CDHPs)

- CDHPs distribute cooled and heated air throughout the house through ductwork.
- Their efficiency is defined by a seasonal energy efficiency ratio (SEER) rating for cooling mode and a heating seasonal performance factor (HSPF) rating for the heating mode.
- There is an existing measure package, SWHC045
- SWHC045 could be updated with new performance maps to reflect latest SEER2/EER2/HSPF2 ratings, and new offerings of inverter driven variable speed compressors
- Offerings that can claim greater savings per unit can be correspondingly incentivized at a higher rate and provide more benefits for the IOU portfolio

R7: Electric Resistance (ER) Heating

- ER heating may be an appealing option in interior zones of large commercial buildings (with very low space heating loads) but this situation is generally never present for residential houses or dwelling units
- This option is less efficient than heat pump-based options (including ductless, central ducted, 120V, and geothermal).
- Many whole-house heat pump designs include ER as a second stage of heating, although this should be avoided if possible.
- Further research into this measure is not recommended for residential measures.

R8: Dual Fuel Heat Pumps

- An option for existing buildings with substantial peak space heating loads
- The heat pump is sized for most days of the year, but the second stage is covered by a gas furnace.
- May be a favorable option on a source energy basis compared to an equivalently sized heat pump with ER heating as the second stage.
- Challenges to implementation may include:
  - Decommissioning of gas systems presents a challenge to ex-post evaluated savings
  - Recent CPUC proposed decision to limit gas incentives
- If this technology is determined to be eligible for future incentives by the Viable Electric Alternatives working group, it should be further evaluated.

Measure Scoring Methodology

Maximum Score 100 points

- Energy savings potential compared to baseline technology= 20 pts
- Product maturity = 10 pts
  - None (0) = Emerging Technology/no commercial production
  - Low (2) = Starting commercial production
  - Medium (6) = Limited commercial production
  - High = (10) Widespread commercial production
- CA Market Size = 30 pts
  - The percentage of statewide square footage or dwelling units that the measure has the potential to be installed in divided by the percentage of the highest scoring residential or commercial value and multiplied by the maximum points value to obtain a normalized score.
- Regulatory Barriers = 20 pts
  - Any regulatory barriers e.g., upcoming code changes, presence of technology in federal/state codes, or CPUC resolutions. Fewer barriers means higher ratings.
- Deemed Feasibility = 20 pts
  - Feasibility of measure in a deemed program and amount of work necessary to create a measure package. Higher ratings indicate better feasibility.

Residential Measure Scoring Results

Measure Number/Name	Energy Savings (20)[a]	Product Maturity (10)	CA Market Size (30)	Regulatory Barriers (20)	Deemed Feasibility (20)	Total Score (100)
R1/Combi HP	20	2	30	5	10	67
R2/120V HP	0	2	28	20	10	60
R4/GSHP	18	10	3	10	10	51
R3/AWHP	11	6	3	15	10	45

[a] Note that this field is normalized to the least efficient all-electric option included in the scoring framework, so a low score is not indicative of a low efficiency technology

Residential Measure Advice Letter Inputs

- CET was run for CZ09 only- based on estimates of preliminary per-unit savings, impacts, RACC, and incremental cost. All measures are assumed to be run as custom, since no deemed measure packages exist for any proposed new measures. **These numbers are tentative estimates and may change as the measure analysis progresses.**

Measure No.	Measure Name	TRC	TSB ($)	kWh	therms	GHG (metric tons)	Source Energy (MMBtu)
R1	Combination DHW+Space Heating Heat Pumps	0.55	$3,354,960	(1,090,612)	186,111	13,968	239,204
R2	120V Heat Pumps	1.30	$842,672	(857,852)	73,196	4,610	78,360
R3	Air to Water Heat Pumps	0.67	$98,319	(65,292)	7,799	541	9,307
R4	Geothermal Heat Pumps	0.37	$160,146	(50,782)	7,799	581	9,838

Next Steps for Residential Measures

Measure No.	Name	Next Steps
R1	Combination DHW + Space Heating Heat Pumps	Pursue measure package. Base and measure cases are clearly defined, savings opportunity is present, products are commercially available and could benefit from promotion.
R2	120V heat pumps	Pursue measure package. Base and measure cases are clearly defined, savings opportunity is present, products are commercially available and could benefit from promotion.
R3	Air to Water Heat Pumps (AWHP)	Pursue additional research to study market size. Possible candidate for future measure package.
R4	Ground Source Heat Pumps (GSHP)	Pursue additional research to study installation/drilling costs. Possible candidate for future measure package.
R5	Ductless Heat Pumps (DHP) (SWHC044)	Update current measure package to add new offerings for VS heat pumps.
R6	Central Ducted Heat Pumps (SWHC045)	Update current measure package to add new offerings for VS heat pumps.
R7	Electric resistance (ER) heating	Do not pursue further research. Better all-electric options exist and should be promoted instead of ER for residential.
R8	Dual fuel heat pumps	The recent CPUC Proposed Decision may preclude incentives for dual fuel equipment in the future. Monitor CPUC Viable Electric Alternatives working group outcomes to see if incentives will be allowed.

Commercial

C1: Air Source Heat Pumps (ASHP)

- Includes three subcategories:
  1. Commercial Unitary Heat Pumps (CUHP)
  2. Air to Water Heat Pumps (AWHP)
  3. Variable Refrigerant Flow (VRF)
- CUHP or Rooftop Units are expected to become a major all-electric space heating solution for small and low-density commercial buildings.
- Any building served by a commercial unitary air conditioner (CUAC) paired with a commercial warm air furnace (CWAF) is a great candidate for an all-electric CUHP system

C1.1: Commercial Unitary Heat Pump	C1.2: Air to Water Heat Pump	C1.3: Air-source VRF HP
		
Trane Precedent (Heat Pump)	Aermec NRL_H, NRB-H	LG Multi V 5 (ARUM)

C1: Air Source Heat Pumps (ASHP)

C1.1: Commercial Unitary Heat Pumps

- Due to its strong fuel substitution potential, CUHPs are currently the only technology covered by an active eTRM measure package (SWHC046) but it only captures medium efficiency CUHPs.
- We propose eventually adding a higher efficiency tier for SWHC046 to capture the upper end of the market.
- Manufacturers are selling CUHP equipment with significantly higher IEER ratings, enabled by variable speed inverter driven compressors and fans such as the Daikin Rebel DPSA/DFSA with IEER ratings of up to 20.

Table 1 SWHC046-02 Highest Efficiency Tiers

Capacity Range (kBtu/h)	Highest Tier Efficiency Rating
<65	18.0 SEER
65-135	16.0 IEER
135-240	15.5 IEER
240-760	14.0 IEER

C1: Air Source Heat Pumps (ASHP)

C1.2: Air to Water Heat Pumps (AWHP)

- AWHPs are typically applied in space heating applications.
- Barriers to adoption:
  - Significantly more expensive than other ASHP options
  - Requires more space than other ASHP options
- As the buildings become larger and more diverse in heating/cooling load profiles, mechanical heat recovery becomes a very attractive addition to the system
- AWHPs used for radiant heating can supply lower hot water supply temperatures and improve system efficiency.

C1.3: Air Source Variable Refrigerant Flow (VRF) Heat Pumps

- VRF heat pumps without heat recovery are a frequently installed all-electric space heating option in commercial buildings.
- Air-source VRFs are better suited for small and medium buildings, while water-source VRFs are more common in large buildings
- VRFs contain large quantities of refrigerant in piping networks distributed throughout the building
- VRF is appropriate for a deemed eTRM measure, though refrigerant impacts and updated ratings due to AHRI 1230-2021 requirements must be considered.

C2: Mechanical Heat Recovery (HR)

"Mechanical heat recovery" – refers to any vapor-compression refrigeration system capable of simultaneously providing space cooling and space and/or domestic hot water heating

- **HR** results in high system COPs
  - Ex: Heating $\boldsymbol{COP_{HP}}$ **≥3.68** for a <75 ton positive displacement equipment (with 120F leaving hot water temperature) without heat recovery; while heating $\boldsymbol{COP_{HP}}$ **≥6.41** is possible for the same system with heat recovery.
- **HR** is a "partial fuel substitution" solution as it can only be leveraged when both heating and cooling loads are available,
- **HR** chiller can satisfy space heating loads for cases with very low space heating loads and very high process cooling loads e.g., data centers in mild climates.
- **HR** chillers are an important stepping stone toward fully electrified commercial buildings and can be incentivized as part of a staged conversion over to all-electric space heating
- Challenges with decommissioning the gas system are less pressing for this option
- Offloading a gas boiler with **HR** chiller is advantageous and should provide substantial ex-post savings

C2: Mechanical Heat Recovery (HR)

C2.1: Air Source Heat Recovery (ASHR) Chillers

- ASHR, sometimes referred to as 4-pipe ASHPs include air-to-refrigerant heat exchanger and then two supply pipes and two return pipes.
- Hot water from ambient air or the waste heat from a chilled water loop can be used as heat sources.
- Can operate similarly to an Air-cooled Chiller if the loads are cooling dominated, e.g., Multistack ARA line.
- Though products exist in the market, ASHRAE 90.1 and Title 24 do not include efficiency rating requirements.

		
Trane CenTraVac with Heat Recovery	York YK Centrifugal with Heat Recovery	Carrier AquaForce 30HX, 30XW

C2: Mechanical Heat Recovery (HR)

C2.2: Water Source Heat Recovery (WSHR) Chillers

- Primarily marketed as a water-cooled chiller with heat recovery capabilities
- “Double bundle” **HR** chillers (6-pipe: Use two condenser coils, one for sending excess energy to a cooling tower, the other for returning energy to the building
- Delivers condenser heat to the building and absorbs energy from the building in the evaporator
- **HR** chillers can be linked to condenser water or chilled water loops (in both cases, delivering hot water). The latter is more efficient since the HR chiller can offload the regular chiller by cooling down the return CHW temperature before enters the cooling only equipment.

		
Multistack VME II	Aermec NXP	ClimaCool UCH

C2: Mechanical Heat Recovery (HR)

C2.3: VRF with Heat Recovery

- VRFs with heat recovery can assign individual indoor units to operate in cooling or heating modes.
- VRF with heat recovery has several disadvantages relative to hydronic heat recovery.
  - long refrigerant lines resulting in pressure losses that are significant vs. hydronic pumps.
  - refrigerant temperature and pressure is set by the highest demand zone in the building- system operates at a much higher lift than the equivalent hydronic HR system.
  - VRF HR must always be configured for high lift (to produce both ~40 °F and ~120 °F refrigerant) to provide space cooling and space heating- limiting its potential during part-load conditions.
  - benefits of VRF with HR may be overstated by its metric, simultaneous cooling and heating efficiency (SCHE).
- Despite the above challenges, VRF HR is commercially available and widely installed.
- VRF systems with both heat pump with and without heat recovery, will be captured later in “C9: ASHP + Mech HR”.

C3: Water Source Heat Pumps (WSHPs)

WSHPs –any equipment with a water-to-refrigerant heat exchange as the heat source or sink, and then either a refrigerant-to-air, refrigerant-to-water, or refrigerant-to-refrigerant heat exchanger delivering or accepting heat from the conditioned spaces

C3.1: Water to Air Heat Pumps (WAHP)

- An established technology that has been on the market for decades
- Products available up to 25 tons
- The fuel substitution measure for this equipment type would involve replacing supplemental boilers with an AWHP (C10).

Table 13: Water to Air DOE Federal Minimum Efficiency Requirements

Size Category (Btu/h)	Cooling Efficiency (EER)	Heating Efficiency (COP)
<17,000	12.2	4.3
≥17,000 and <65,000	13.0	4.3
≥65,000 and <135,000	13.0	4.3

C3: Water Source Heat Pumps (WSHPs)

C3.2: Water to Water Heat Pumps (WWHPs)

- WWHP is heating dominated- similar to WSHR Chillers, discussed in C2.2, which is cooling dominated
- 2013 Johnson Controls, Inc. slide deck discusses the differences in technology.
  - Chilled water setpoint is controlled for HR chillers.
  - Got water supply temperature setpoint for WWHPs.

C3.3: Water Source VRF (WS-VRF)

- WS-VRF- popular in large buildings with insufficient roof space for air source VRF equipment.
- WS-VRF is installed within the building- the resulting water loop is connected to cooling tower and boiler.
- WS-VRF system can include or exclude heat recovery capabilities.
- Similar to WAHPs, WS-VRF could be all-electric if an AWHP were used instead of a boiler for supplemental heat.

C4: Ground Source Heat Pumps (GSHP)

- GSHP is similar to residential counterpart, described in R4
- Offer high efficiency, low maintenance cost and take up less space
- GSHPs offer a high level of reliability over periods exceeding 25 years and a very high level of owner satisfaction
- However, commercial GSHPs penetration into the California market has been low
    - High drilling costs due to the rocky soil in California and significant installation costs of ground heat exchangers

C5: Thermal Energy Storage (TES)

- TES- an emerging technology in the all-electric HVAC space.
- TES is a component technology that can be paired with other elements (such as ASHPs and/or HR chillers) to achieve complete electrification of space heating.
- TES for space heating has been identified as a promising technology to pair with heat recovery (especially mechanical heat recovery)
  - HR only works during simultaneous cooling and heating periods.
  - That requirement disappears in TES since heat rejection during cooling can be stored for later usage in space heating.
- TES can be designed around several temperature bands- hot water (e.g., 110 – 140 °F), condenser water (e.g., 40 – 90 °F), chilled water (e.g., 32 – 65 °F), or ice/water (e.g., 25 – 45 °F)

C6: Electric Resistance (ER) Heating

ER space heating shows a strong targeted measure opportunity in the future – see table below.

- Although ER heating compares unfavorably to Heat Pumps and HR options due to their higher efficiencies, HPs suffer from thermal and pumping penalties due to long refrigerant or hydronic piping throughout the building
- ER heating can be an attractive proposition when paired with “other measures”, and deployed in a zone with very low space heating loads

Measure Aspect	Description
Base case	Boiler
Measure case	Wire-to-air ER heating in the zone VAV box (i.e., not an electric boiler or an ER heating coil in a central AHU)
Building types	Large buildings with interior zones that rarely experience space heating loads, buildings in mild climate zones, highly efficient buildings (e.g., those with an efficient envelope or well performing HVAC controls).
C&S information	ER heating is prescriptively banned by Title 24 Part 6 at section 140.4(g). ER heating can be leveraged if the performance compliance approach is used.
Other information of note	There is an active CASE proposal for Title 24-2025 to loosen the prescriptive ban on wire-to-air ER heating when other EE measures are leveraged.

C7: Waste Fluid Heat Recovery

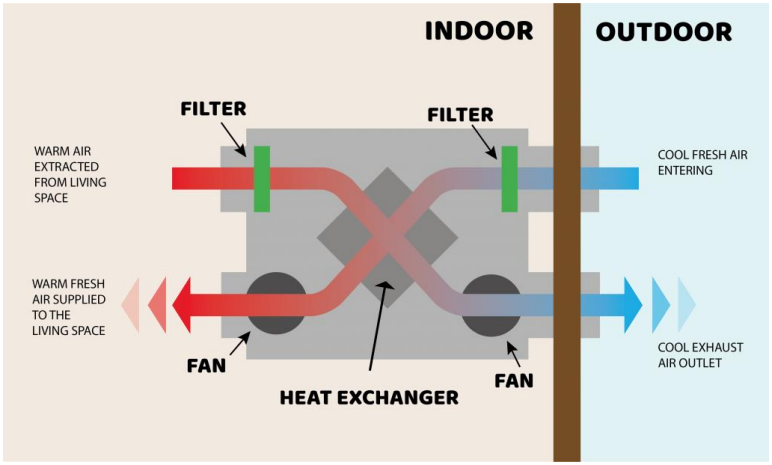
Recovers the waste heat from fluid leaving a building to preheat (or precool) another fluid stream

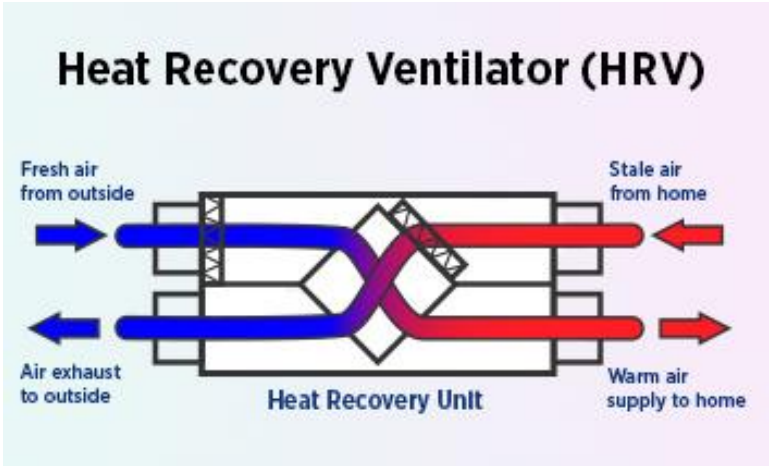
- Ventilation air heat recovery and wastewater heat recovery.
  - Doesn't include compressor pumping heat but rather passive heat transfer through a heat exchanger.
  - Mechanical HR and waste fluid HR can complement each other, if cost effective.
  - For example, a wastewater HR system can preheat an intermediate water loop that then offloads a water-to-water heat pump (a.k.a. a HR chiller) to supply hot water to VAV boxes.
  - Waste Fluid HR, similar to Mechanical HR, is a "partial" electrification measure, only offsets a fraction of the building's gas energy usage for space heating
  - Can be coupled with other technologies (e.g. C12: ASHP + Waste Fluid Heat Recovery)

C7: Waste Fluid Heat Recovery

C7.1: Exhaust Air Heat Recovery (EAHR)

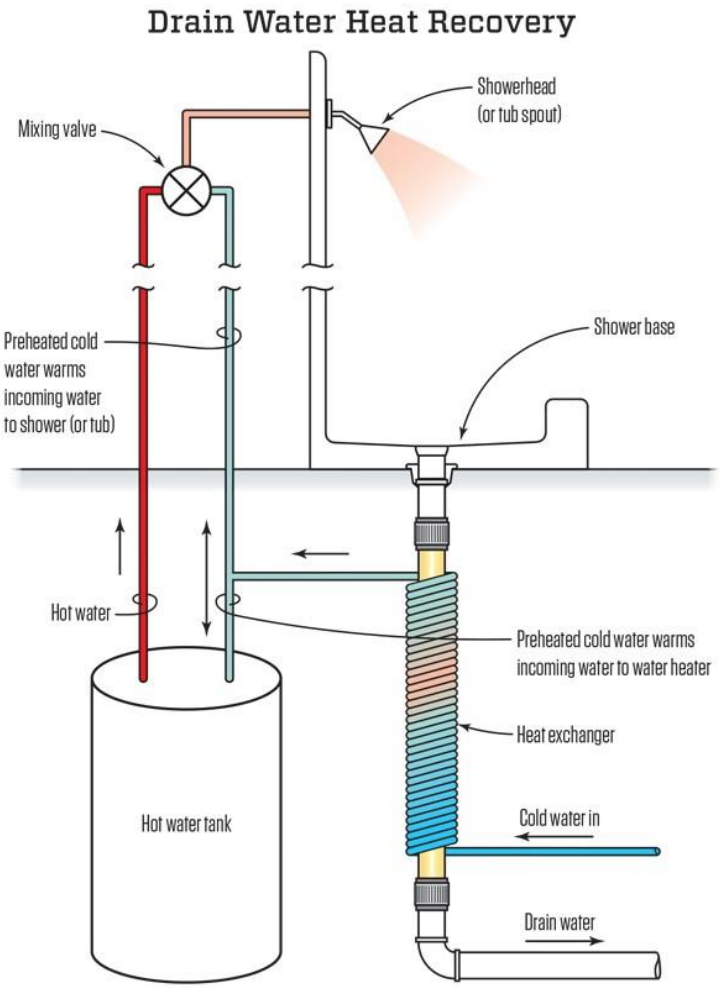
- Recover energy from the exhausted airstream from building to the incoming airstream through a heat exchanger.
  - In summer, incoming ambient air at 90F can be cooled by the outgoing air from building at 75F.
  - Contrarily in winter, exhaust air would preheat the incoming fresh air.
  - In 2022, the Title 24 CASE Team proposed a measure requiring EAHR .





C7: Waste Fluid Heat Recovery

- **C7.2: Wastewater Heat Recovery (WWHR)**
- Similar to EAHR, a wastewater stream is leveraged as a heat source or sink depending upon whether the building requires heating or cooling.
- For example, wastewater from showers or dishwasher would be warmer than toilet wastewater.



C8: Single Zone Wall Mounted Equipment

- This category includes two types of unitary HVAC equipment: package terminal heat pumps (PTHP) and single package vertical heat pumps (SPVAC/SPVHP).
- The two categories are similar but differ for their unique form factors and applications

Measure Aspect	Description
Base case	SZ wall-mounted AC equipment + gas heating
Measure case	SZ wall-mounted HP equipment
Building types	PTHP: hotel/motel, multifamily buildings (e.g., dormitories, condominiums, apartment buildings), education SPVHP: relocatable classroom, multifamily buildings
C&S information	Both PTHP and SPVHP are federally regulated products. The industry standard test procedure for PTHP is AHRI 310/380 and SPVHP's is AHRI 390, both of which are referenced by DOE. Both PTHPs and SPVHPs are rated using EER for cooling-mode and COP_{47} for heating-mode.
Other information of note	DOE is currently in the process of re-analyzing these products (homepages for PTHP and SPVHP) which may result in changes to the equipment rating and/or energy conservation standard levels.

C8: Single Zone Wall Mounted Equipment

C8.1: Packaged Terminal Heat Pump (PTHP): Single Zone Wall Mounted Equipment

- PTHPs are unitary systems, meaning the single heat pump unit can provide both heating and cooling.
- Commonly used in hotels, motels, senior housing facilities, hospitals, condominiums, apartment buildings, add-on rooms and sunrooms
- 208/240 Volt with heating/cooling capacity ranging from 1.5 to 7 kW (5,000–24,000 BTU/h) nominal
- Most PTAC systems have electric resistance heat, and hence PTAC to PTHP replacements will likely not be considered fuel substitution.

		
Source: Islandaire PTAC EZ Series 42	Source: Friedrich PDH09K3SGR3	Source: Ice Air PTAC RSXC09
Quieter, cooling only or heat pump with back up electric heat	R32 Unit with 9.4 kBTU EER=12.1	Claimed to be world's first cold climate Heat Pump- heating down to -5 °F

C8: Single Zone Wall Mounted Equipment

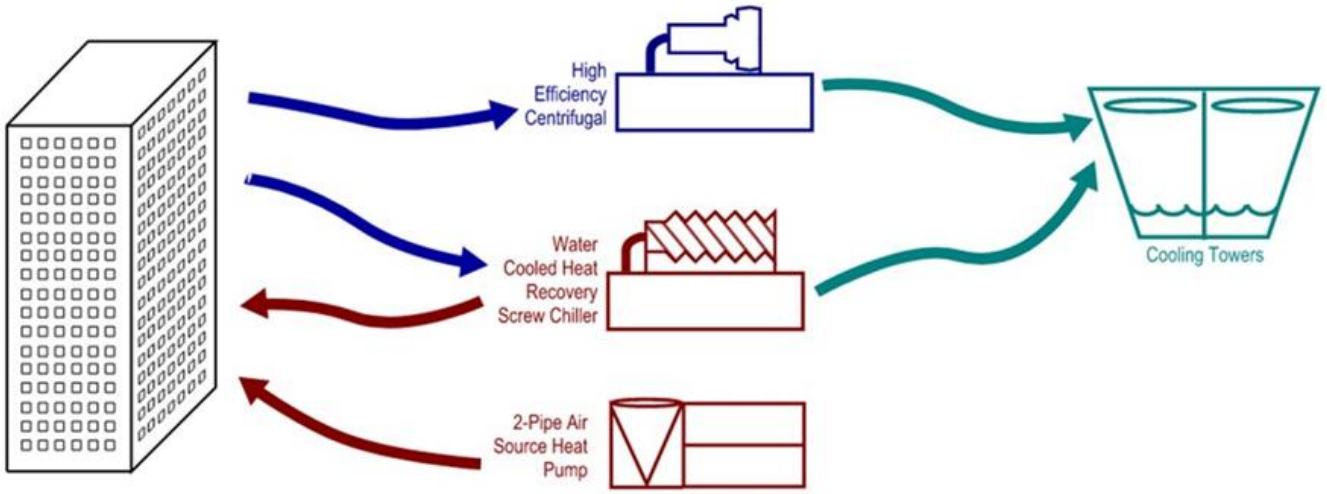
C8.2: Single Packaged Vertical Heat Pumps (SPVHP): Single Zone Wall Mounted Equipment

- SPVHPs are through the wall systems with the condenser and evaporator stacked vertically.
- Interior and Exterior Wall systems are respectively mounted at interior or exterior Walls
- Heating/cooling capacity ranging from 0.5-5 tons
- SPVHPs can be an attractive fuel substitution for buildings that use SPVAC systems with gas heat .

	
Source: GE Zoneline	Source: Eubank
Interior mount SPVHP used in multifamily applications.	Exterior mount SPVHP used in portable buildings

C9: ASHP + Mech HR

- Cooling and heating loads must “overlap” for the HR equipment to be used effectively.
- Mech HR allowing downsizing of ASHP
- Steady process loads sites, such as hospitals, data centers, and mixed-use buildings, are good candidates
- ASHP + Mech HR constitutes a complete all-electric system –**custom** measure in the short term



ASHP + Mechanical Heat Recovery (Source: Brandon Gill, Taylor Engineers)

C10: ASHP + WSHP

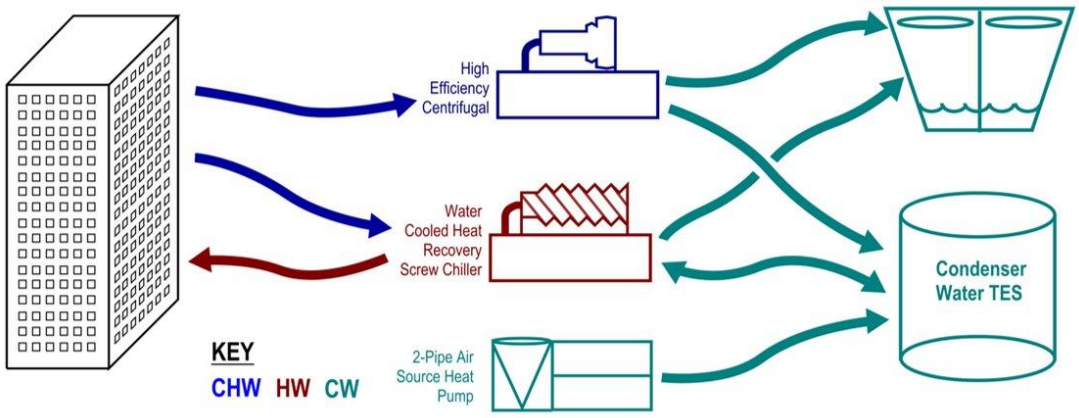
Replace the trim boiler of a WSHP system with an AWHP.

- Several configurations exit to mix-and-match for building needs e.g., AWHPs, WWHPs, WS-VRFs, WAHPs.
- Flexible systems- initially as “custom” incentive program; can be deemed measure packages later
- AWHP+WAHP should be considered for “deemed” measure in the near term- savings can be quantified using BEM

C11: ASHP + Mech HR + TES

Time Independent Heat Recover (TIER)

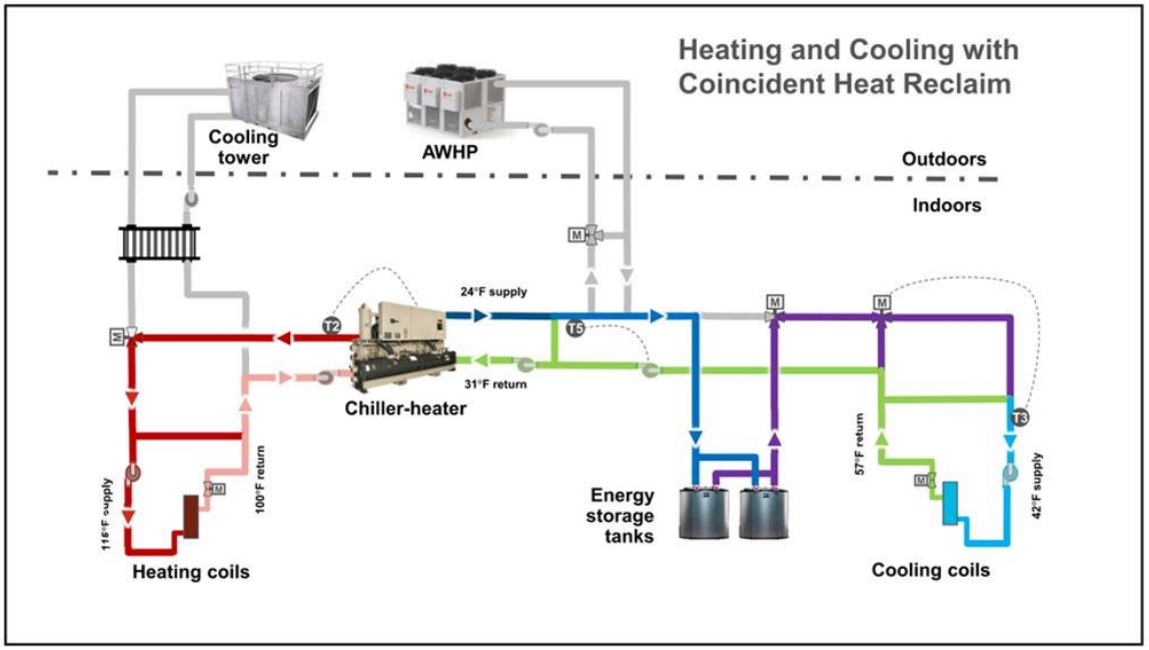
- Cascading all-electric systems to ensure all chillers are used in low-lift conditions
- Cooling chillers- with 40°F chilled water supply temp to 8 °F condenser water leaving temperature
- HR chillers with 60 °F evaporator supply temp to hot water supply temp, from 110°F to 140°F
- In California's mild climate zones, energy recovered from cooling loads alone can satisfy heating loads
- Traditional TES tank is used for cooling peak shifting, not for heat recovery
- TIER TES is sized to meet heating loads on a design heating day during all hours of the day
- Load shifting allows the TIER design to save space, improve efficiency and reduce cost as well as ASHP capacity dramatically
- TES tank capacity should be maximized to reduce overall project costs and improves plant efficiency



C11: ASHP + Mech HR + TES

Storage Source Heat Pump

- Ice TES is “discharged” during winter afternoons and then “charged” during winter morning warm-up using a high-lift heat recovery chiller system
- Ice storage offers space efficiency per unit of capacity
- Attractive in limited space requirements and very cold climates- for some California areas



Other Commercial Measures

C12: ASHP + Waste Fluid Heat Recovery

- ASHP (including CUHPs, AWHPs, and AS VRFs) PLUS some form of waste fluid heat recovery
- Attractive in extreme climates, such as CZ15 or CZ16.
- Can be part of a broader AWHP or VRF measure package

C13: ER Heating + Other measures (EE Improvements, PV, Solar Thermal, Battery)

- For existing sites with boiler systems, possible cost-effective upgrades include HVAC controls, PV, battery storage, and ER heating ⇒ eliminating need for hydronic or refrigerant piping
- For reduced space heating loads using efficiency opportunities, ER heating can be an appealing fuel substitution option

C14: Hybrid of ASHP + Mech HR + TES + ER Heating

- Potentially very efficient solution ⇒ Combining best qualities of heat pump + HR/TES systems with ER heating for very low load zones
- May be pursued as "custom measures" and perhaps ET studies ⇒ for tradeoffs between ER heating and more efficient (but more costly) heat pump and/or heat recovery-based designs

Other Commercial Measures

C15: Energy Efficiency (EE) + Distributed Generation (DG)

- EE/DG pair well with space heating fuel substitution efforts ⇒ shrinking peak heating loads
  - EE measures include building envelope improvements, HVAC controls retrofits, reducing hot water supply temperature (HWST) to reduce thermal losses
  - DG measures include on-site solar PV, battery storage, and solar thermal assisted hot water
- These opportunities can be further quantified for potential measure package modification/development

Commercial Measure Scoring Results

Measure Number/Name	Energy Savings (20)[a]	Product Maturity (10)	CA Market Size (30)	Regulatory Barriers (20)	Deemed Feasibility (20)	Total Score (100)
C1.2/AWHP	3	6	30	15	15	69
C1.3/AS-VRF	3	10	30	5	15	63
C2/Mech HR	12	6	16	10	10	54
C10/AWHP+WSHP	3	6	6	20	15	50
C9/ASHP+Mech HR	11	2	18	10	5	45
C8/PTHP/SPVHP	0	8	0	20	10	39
C11/ASHP+Mech HR+TES	20	2	6	5	5	38

[a] Note that this field is normalized to the least efficient all-electric option included in the scoring framework, so a low score is not indicative of a low efficiency technology

Commercial Measure Advice Letter Inputs

- CET was run for CZ09 only- based on estimates of preliminary per-unit savings, impacts, RACC, and incremental cost. All measures are assumed to be run as custom, since no deemed measure packages exist for any proposed new measures. **These numbers are tentative estimates and may change as the measure analysis progresses.**

Measure No.	Measure Name	TRC	TSB ($)	kWh	therms	GHG (metric tons)	Source Energy (MMBtu)
C1.2	Air to water heat pumps (AWHP) w/o heat recovery	0.57	$1,371,056	(1,061,485)	135,856	13,210	226,200
C1.3	Variable refrigerant flow (VRF) heat pumps w/o heat recovery	0.92	$905,102	(906,529)	99,953	6,854	116,712
C2	Heat recovery chillers (excluding VRF HR)	2.02	$497,722	(11,654)	17,949	2,199	35,398
C8	Single Zone Wall-Mounted Equipment	2.05	$60,956	(39,096)	5,002	276	4,638
C9	ASHP + Mech HR (including AWHP and VRF with HR)	0.46	$822,783	(326,227)	62,611	6,475	111,235
C10	WSHP +ASHP	0.17	$36,812	(32,657)	4,179	311	5,071
C11	ASHP + Mech HR+TES	0.35	$196,018	(14,129)	8,005	1,134	15,404

Next Steps for Commercial Measures

Measure No.	Name	Next Steps
C1	• C1.1: Air to air heat pumps (a.k.a. commercial unitary heat pumps or CUHP) • C1.2: Air to water heat pumps (AWHP) • C1.3: Air source VRF heat pumps without heat recovery	• C1.1: Update SWHC046 with offerings for VS CUHPs • C1.2: Pursue measure package (in conjunction with C9.2 and the C10 'AWHP to WAHP' scenario) • C1.3: Pursue measure package (in conjunction with C9.3)
C2	• C2.1: Air source HR chillers • C2.2: Water source HR chillers • C2.3: VRF with HR	• C2.1: Pursue measure package for partial FS. Clear base & measure case and savings opportunity. • C2.2: Pursue measure package for partial FS. Clear base & measure case and savings opportunity. • C2.3: Pursue with other offerings (i.e., C9.3)
C3	• C3.1 Water to air heat pumps (WAHP) • C3.2 Water to water heat pumps (WWHP) • C3.3 Water source VRF (WS-VRF)	Since this is generally a 'component' technology, pursue all as part of other offerings (such as C10, a consolidated VRF offering, or other measure packages devised beyond the 15 identified in this list).
C4	Ground Source Heat Pump (GSHP)	Conduct additional research on installation/drilling costs. Explore for potential as a future 'component' or complete system technology for promotion.
C5	Thermal Energy Storage (TES)	Pursue as part of other offerings (e.g., C11).
C6	Electric Resistance (ER)	Pursue as part of other offerings (e.g., C13, C14).
C7	• C7.1: Exhaust air heat recovery • C7.2: Wastewater heat recovery	Consider as a standalone "partial" FS measure. Most likely pursue as offerings within another measure package (e.g., C12).
C8	• C8.1: Package Terminal Heat Pump (PTHP) • C8.2: Single Package Vertical Heat Pump (SPVHP)	Pursue additional research to quantify the nature of the heating side of current PTAC and SPVAC systems. Determine the prevalence of PTAC + gas furnace vs. PTAC + electric resistance. Perform analogous analysis for SPVACs. This will inform the magnitude of the FS opportunity.

Next Steps for Commercial Measures

Measure No.	Name	Next Steps
C9	ASHP + Mech HR • C9.1: CUHP + Mech HR • C9.2: AWHP + Mech HR • C9.3: VRF+ Mech HR	• C9.1: Pursue some additional research to better quantify whether this system combination merits a measure package. Pursue with custom measures. • C9.2: Pursue measure package (in conjunction with C1.2 and C10) • C9.3: Pursue measure package (in conjunction with C1.3)
C10	ASHP + WSHP	Pursue measure package, particularly for the condition with an AWHP replacing a gas boiler as part of a WAHP system. We recommend combining with a measure package (as additional offerings) drawing from C1.2 and C9.2. Research if additional combinations of ASHP + WSHP are appropriate for a measure package(s). Pursue with custom measures to gather data.
C11	ASHP + Mech HR + TES	Pursue with custom measures and perform additional research and data gathering activities that can lead to a future deemed measure package. This system configuration is a promising long-term all-electric solution for large buildings.
C12	ASHP + Waste fluid heat recovery	Pursue as offerings combined with other ASHP measure packages.
C13	Electric Resistance bundled with additional measures (envelope improvement, HVAC controls upgrade, solar PV, battery)	Pursue additional research into understanding the peak load impacts of ER heating and the savings impact of bundling ER with other measures.
C14	ASHP + Mech HR + TES in exterior zones and ER for interior zones	Pursue additional research into peak load impacts of ER heating, consider pursuing as a custom measure.
C15	EE/DG measures (Lower HWST, HVAC controls, building envelope improvement, PV+Storage, Solar Thermal assisted hot water)	Perform additional research into the interaction between EE/DG measures and space heating electrification.

Thank you!

Bryan Boyce
Energy Solutions
(510) 550-8518
bboyce@energy-solution.com