LG Multi V™ Dedicated Outdoor Air System (DOAS) Energy Analysis

Image of the LG Split DOAS (Dedicated Outdoor Air System) https://images.lghvac.com/a2x2S00000Ca3A3/6f544933-9e42-2339-bba4-8901f940e3c2/hi-res/Split_DOAS.jpg

Contents

for entering that data. The calculation results and reports described by this guide are meant to aid the system designer and are not a substitute for design services, judgment, or experience.

Executive Summary

LG Electronics U.S.A., Inc.'s Air Conditioning Technologies team conducted energy efficiency option analysis for an office building. The study investigated the potential for reduced HVAC energy costs and improved thermal comfort when operating an LG dedicated outdoor air system (DOAS). To provide a concrete basis for the analysis, the proposed building was built using Department of Energy (DOE) climate zones 1A, 2A, 3A, 3B, 4A, 4C, 5A, and 6A. LG ACT created several computer simulations of both the proposed design and baseline design, all using the same floor plan, occupancy schedules, lighting density, ventilation, and envelope types. The primary HVAC system is designed for building cooling and heating loads with respect to climatic conditions. Only the DOAS type and associated efficiencies are different. Simulations demonstrate that the proposed design using an LG DOAS provides annual energy cost savings and thermal comfort when compared to basic building systems.

Table 1: Summary of LG Compact Type DOAS Ventilation Energy Cost % Savings.[1]

Location (Climate Zone)	Proposed Ventilation Energy Cost Savings (%)*		Proposed HVAC Energy Cost Savings (%)*	
	Vs Packaged Type DOAS	Vs Packaged ERV Type DOAS	Vs Packaged Type DOAS	Vs Packaged ERV Type DOAS
Miami, FL (1A)	77%	67%	22%	12%
Houston, TX (2A)	77%	72%	31%	26%
Atlanta, GA (3A)	76%	67%	33%	27%
Los Angeles, CA (3B)	87%	84%	24%	19%
New York, NY (4A)	72%	66%	28%	19%
Seattle, WA (4C)	71%	65%	32%	19%
Chicago, IL (5A)	59%	49%	22%	16%
Madison, WI(6A)	59%	52%	23%	18%

(*Leaving air supply is neutral, compared to the baseline, which is Packaged Type DOAS and Packaged ERV Type DOAS.)

[1] **Legal Disclaimer:** The models described in this report are intended to demonstrate the potential cost-effectiveness of possible energy improvements for new facilities under the conditions as identified in the white paper. The choice of models was subject to the professional judgment of LG Electronics U.S.A., Inc., in accordance with industry standards. The models and conclusions of this report do not guarantee actual energy costs or savings.

Introduction

Ventilation

Commercial and residential buildings are required by building codes to provide outdoor air ventilation during occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE®)[2] Standard 62.1 provides ventilation guidelines for acceptable indoor air quality that can accommodate residents and occupants and minimize harmful health effects.

What is a Dedicated Outdoor Air System (DOAS)?

Packaged rooftop units are the most commonly used HVAC application type of what for all building types. If the outside air requirement is minimal, such as a climate where moisture control is not a problem, the existing packaged rooftop unit can effectively control the outside air required. Conventional rooftop units have some limitations with respect to outdoor air conditioning, however, including operating range or poor thermal comfort, especially low energy efficiency.

A DOAS is designed to provide a separate ventilation system, rather than include ventilation as part of the air conditioning system. In other words, DOAS can provide the necessary ventilation air independent of the building's primary HVAC system used to maintain room temperature. This approach to handling ventilation air allows for excellent humidity control by limiting the major sources of direct humidity in the ambient humidity carried by the ventilation air in most buildings. Removing enough moisture from the ventilation air so that the DOAS matches the internal load of the building increases energy efficiency. The DOAS enables the primary cooling system to operate at a higher evaporation temperature with separate, intelligent cooling to achieve energy savings. More energy savings can be realized by providing only the necessary ventilation air, or by using an energy recovery ventilator from the building's exhaust air to prevent ventilation air.

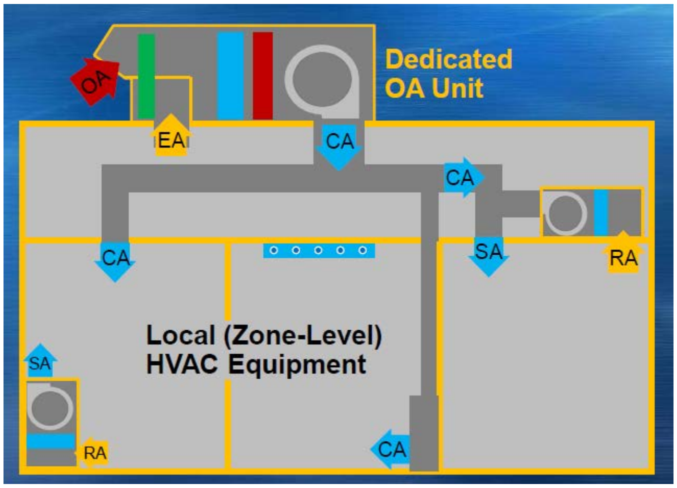
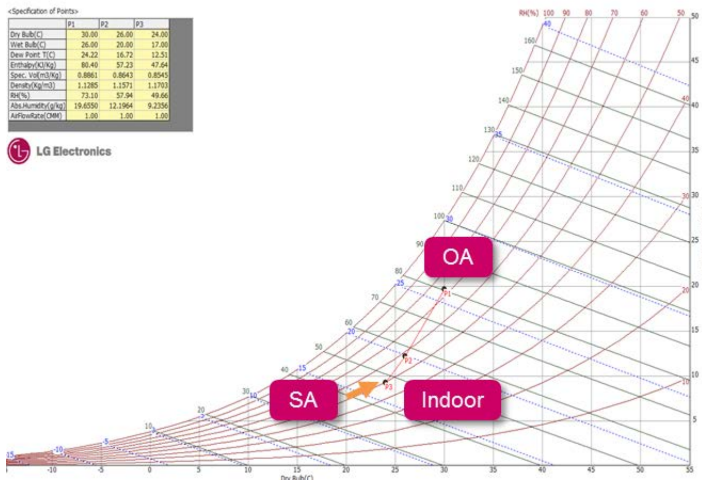


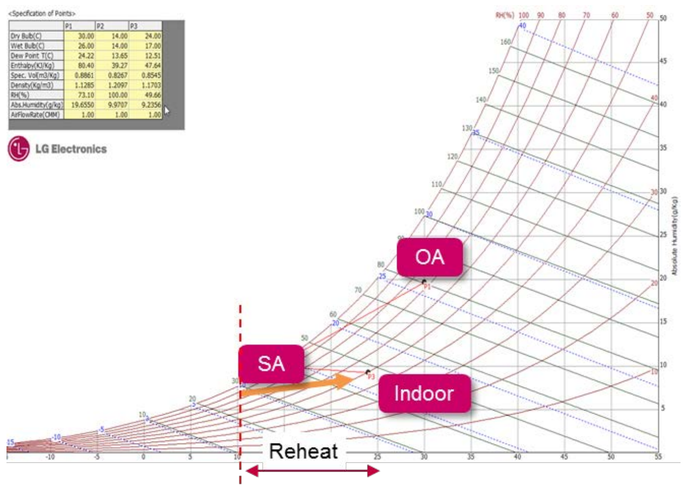
Figure 1: Example of a Dedicated Outdoor Air System (DOAS) (Image courtesy of ASHRAE. 2012 Webcast[3]).

[2] ASHRAE® is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[3] http://www.ashrae.org/doaswebcast.



(a) Direct Ventilation Process.



(b) DOAS process.

Figure 2: Psychrometric Process of Outdoor Air Treatment.

Selecting the LG Dedicated Outdoor Air System (DOAS)

LG's DOAS brings fresh outdoor air indoors to improve air quality without sacrificing energy efficiency. These systems are designed specifically for LG Variable Refrigerant Flow (VRF) systems, and can be used in a variety of settings such as schools, offices, retail stores, and multi-family housing. By applying LG's technology and design, the system can save energy, ceiling space, and installation costs. The features and benefits of an LG DOAS include:

- Baseline (1): Packaged Type DOAS: 1,000 – 13,500 CFM, 5 – 70 Tons.
    - EER: 9.4 (AHRI 340/360); IEER: 11.7 (AHRI 340/360), Gas heat (80%).
    - Designed to heat, cool, and dehumidify 100% outdoor air.
    - Four (4) to six (6) row direct expansion (DX) cooling coil.
    - Modulating hot gas reheat coil for dehumidification mode.
    - Variable capacity digital or inverter scroll compressor(s).
    - Direct drive supply fan with variable-frequency drive (VFD).
    - Discharge air control with duct sensor for field mounting.
    - 2" MERV 8 filters for supply air.
    - Configurable for down discharge or side discharge.
    - Gas heat with 4:1 turndown.

Figure 3: LG Packaged Type Dedicated Outdoor Air Systems (DOAS).[4]

[4] https://lghvac.com/commercial/product-type/?productTypeId=a2x44000003XR0s&iscommercial=true&class=Air%20Technologies.

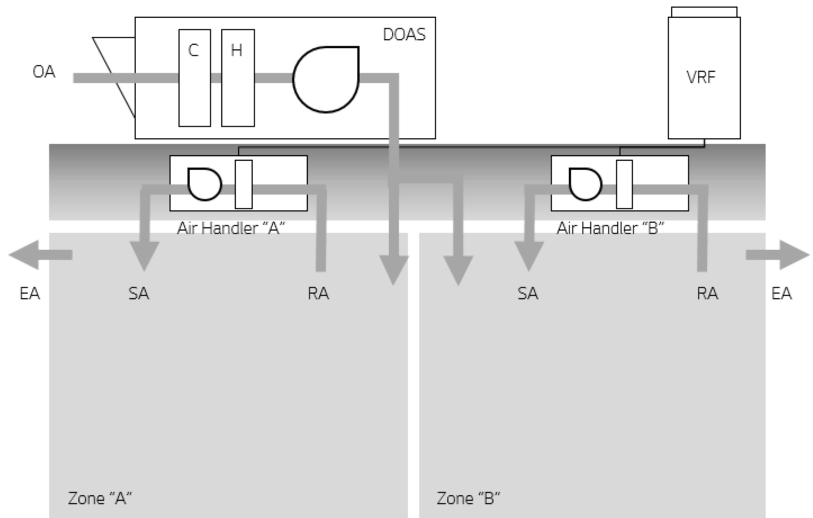


Figure 4: Example Ventilation Configurations for Packaged Type DOAS.

- Baseline (2) : Packaged type DOAS + ERV also have options as follows:
  - EER: 9.4 (AHRI 340/360); IEER: 11.7 (AHRI 340/360); Combined EER: 14.3, Gas heat (80%).
  - Designed to heat, cool, and dehumidify 100% outdoor air.
  - Four (4) to six (6) row direct expansion (DX) cooling coil.
  - Modulating hot gas reheat coil for dehumidification mode.
  - Variable capacity digital or inverter scroll compressor(s).
  - Direct drive supply fan with variable-frequency drive (VFD).
  - 2" MERV 8, 11, or 14 filters.
  - Airflow monitoring (OA or supply fan inlet cone).
  - Filter pressure switch or gauge.
  - Strip heater in control panel (for climates lower than 0°F).
  - Electric preheater for ERV wheel.
  - Heat wheel rotation sensor.
  - Heat wheel Variable Frequency Drive (VFD).
  - Gas heat with 4:1 turndown.

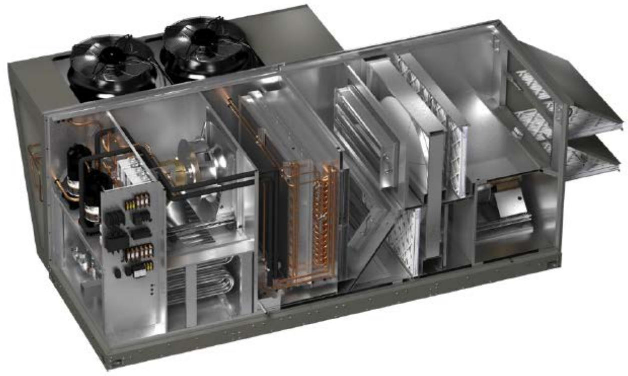


Figure 5: LG Packaged Type with Energy Recovery Wheel Dedicated Outdoor Air Systems (DOAS).[5]

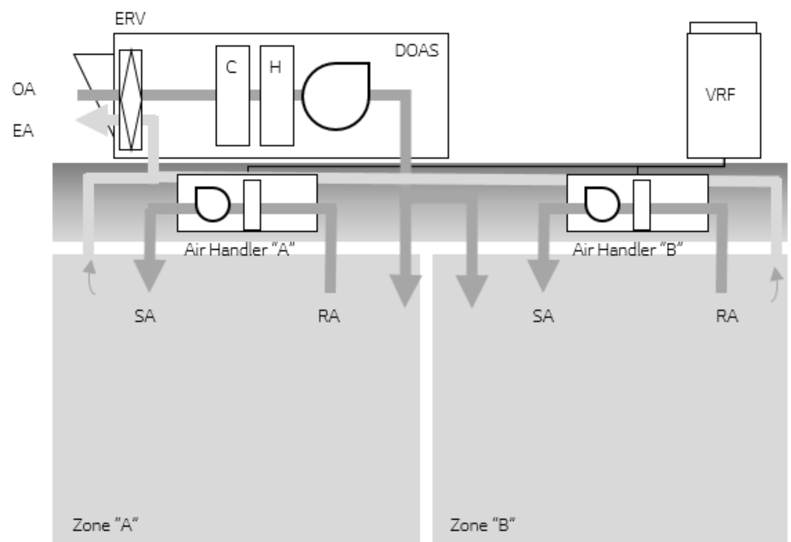


Figure 6: Example Ventilation Configurations for Packaged Type DOAS + ERV Wheel.

- Proposed : Split-Type Compact DOAS also have options as follows:
  - Varying outdoor air temperatures can be conditioned using energy efficient LG VRF technology.
    - Multi V VRF Condensing Unit (EER: 14-18, COP: 4.0-4.7).
    - Heat pump operation down to 14°F without heater.
  - Solution for high rise buildings with ceiling mounted applications.
  - Up to four (4) modules in a combination (combination ratio 50~110%).
  - Direct drive supply fan with an Electronically Commutated Motor (ECM).

[5] https://lghvac.com/commercial/product-type/?productTypeId=a2x44000003XR0s&iscommercial=true&class=Air%20Technologies.

- o 2" MERV 8 supply, outside air filter.
- o Flexible design allows matching the outdoor unit to meet local outdoor air design conditions.

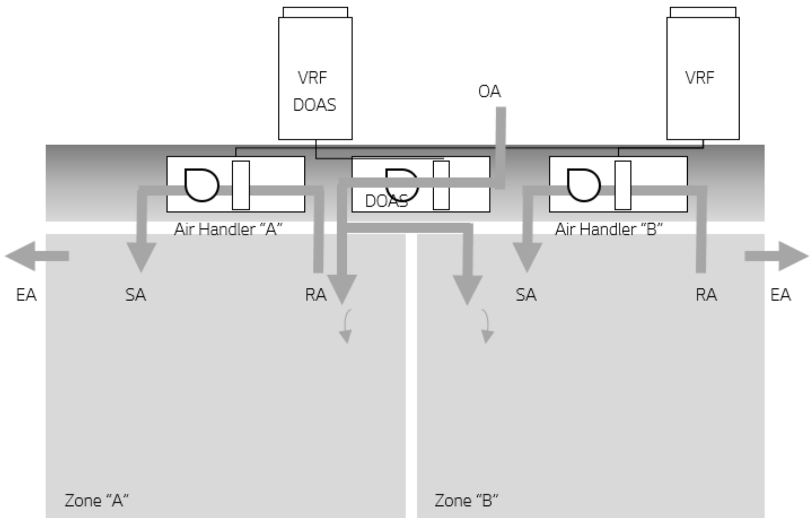


Figure 7: Example Ventilation Configurations for Split Compact DOAS.

Figure 8: Multi V VRF Condensing Unit with Split-Type DOAS Indoor Unit.[6]

[6] https://lghvac.com/commercial/product-type/?productTypeId=a2x2S00000Ca3A3&iscommercial=true&class=Air%20Technologies.

Designing the Outside Air Supply Air Conditions

The operating mode for the dedicated outdoor air system is based on the current outdoor air conditions. Outdoor temperature and humidity sensors are used to calculate the outdoor air dew point, and compare it to the desired leaving-air conditions. This determines whether the unit operates in Cooling Mode, Heating Mode, Dehumidification Mode, or if conditions are sufficient for the unit to operate in Ventilation Only mode.

- Cooling
  - If the outdoor temperature is higher than the cooling set point, the unit will operate in cooling mode. In this mode, the unit capacity is adjusted to cool the outdoor air (OA) to the leaving air temperature.

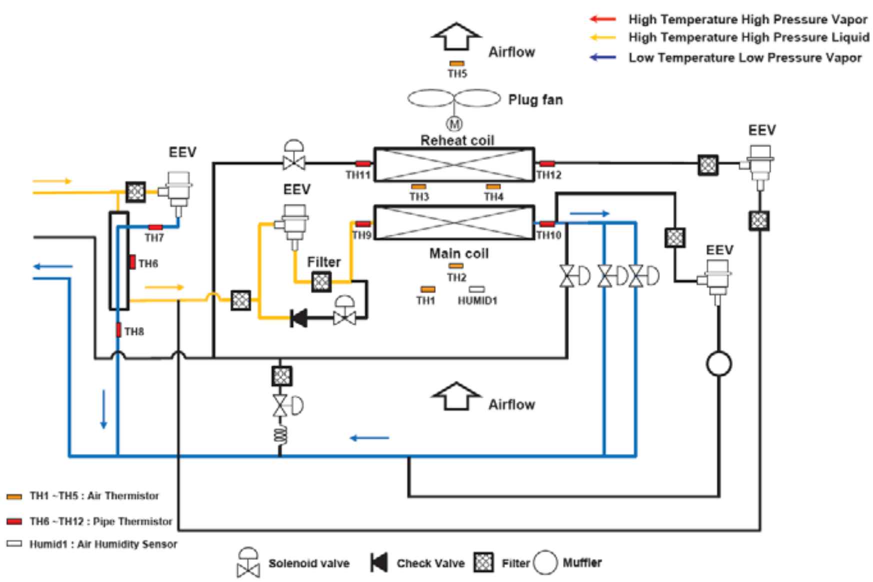


Figure 9: Refrigerant Piping Diagram (Cooling Mode).

- Heating
  - If the outdoor temperature is lower than the heating set point, the unit will operate in heating mode. In this mode, the unit capacity is adjusted to heat OA to the leaving escape air dry bulb temperature (CA) (heat pump can operate down to 14°F without auxiliary heater).

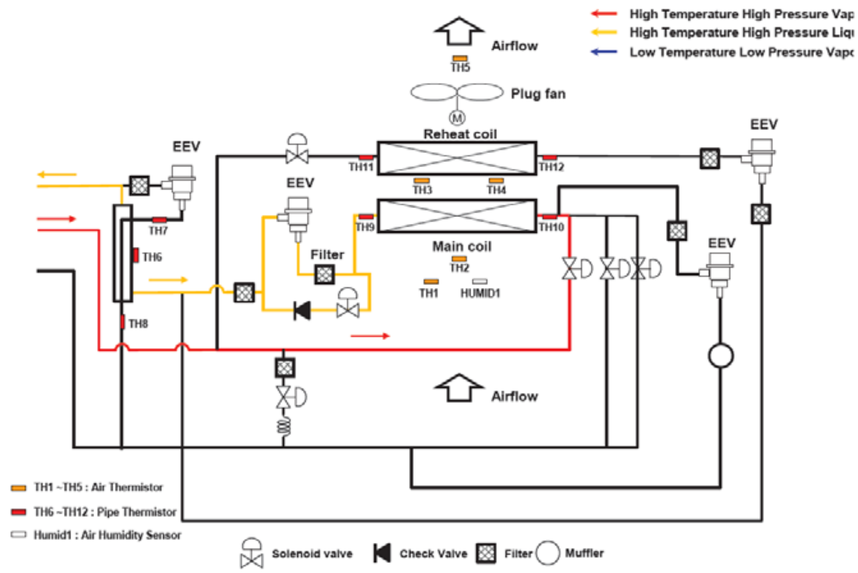


Figure 10: Refrigerant Piping Diagram (Heating Mode).

- .Dehumidification
  - o Dehumidification mode is initiated based on adjustable outdoor air dew point temperature set points. Modulating hot gas reheats coil for dehumidification mode. Air handler controller senses high outdoor air humidity and provides dehumidification mode.

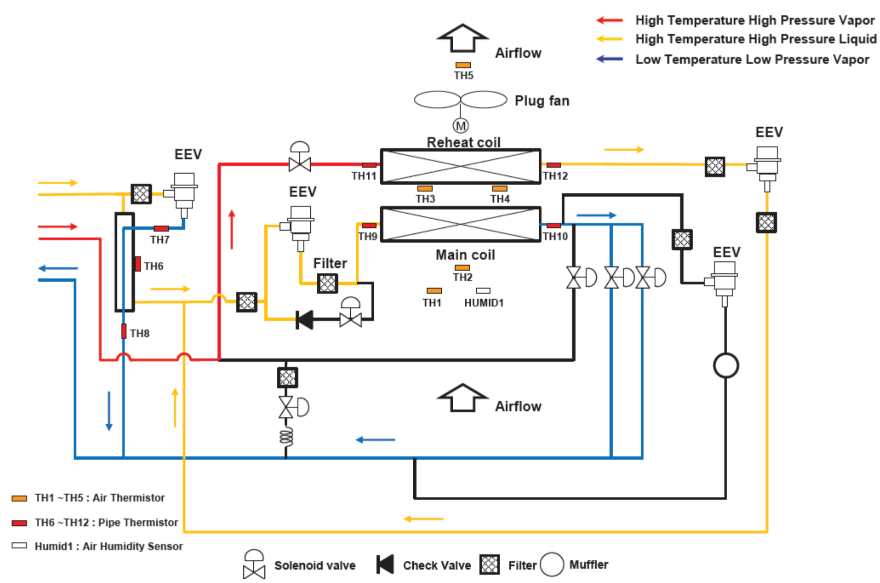


Figure 11: Refrigerant Piping Diagram (Dehumidification).

- Ventilation only.
  - o The unit operates in ventilation only mode when the outdoor temperature is below the cooling set point but above the heating set point. In this mode, the fan continues to run, but both the compressor and heater are turned off.

The basic concept of the DOAS is to deliver conditioned outside air to every space in the building. There is a good deal of flexibility inherent in a DOAS' operation because latent OA loads (mainly from occupants receiving OA of the specified flow rate) are eliminated and space loads are reduced in the primary system.

DOAS Supply Air Temperature

Mechanical engineers can design the DOAS to supply air at the same temperature (neutral air), or at the temperature that dehumidifies the air (cold air) in the building.

- Neutral air systems provide air at a temperature that is easy to mix with the occupied zone air. For this reason, it can be introduced directly indoors using traditional diffusers. VRF applications may benefit from the neutral air concept. Because ventilation air can be introduced directly into the space, the ventilation air can be completely isolated from the primary cooling system, allowing the primary system to vary the amount of re-circulated air to match the detectable load in space. Engineers should consider reheating, however, when considering the use of a neutral air DOAS. Neutral air systems almost always contain a reheat load, because the outside air temperature drops below the dew point temperature to dry the air. This usually keeps the coil at a temperature of about 50°F. Neutral air systems are designed to supply air at room temperature, so in most cases, the 50°F air should be reheated to about 20°F to 30°F. Generally, a DOAS is required that includes a hot gas reheat heat coil / control device that captures rejected heat from the condenser side of the DOAS unit.
- Cold air systems do not require reheating, or only reheat a small part of the system. The outside air ambient temperature will be lower than the outside air dew point temperature, and will be distributed in that condition because the air will dry. Unfortunately, it is sometimes difficult to mix cold air directly with the outside air because much cooler air tends to fall quickly, and air drafts can cause discomfort.

Energy with DOAS Supply Air Temperature

Table 2: Example Energy Consumption (Packaged Type DOAS, Atlanta GA).

Control Options	Option A (DOAS LAT: Neutral)	Option B (DOAS LAT: Slightly Cold)	Option C (DOAS LAT: Cold)
Indoor set point temperatures Cooling: 75°F	Leaving air temperature: 75°F	Leaving air temperature: 65°F	Leaving air temperature : 55°F
Ventilation Energy	51.4 MBtu	65.8 MBtu	92.9 MBtu
Indoor HVAC Energy	153.6 MBtu	150.3 MBtu	145.5 MBtu
Building HVAC Energy Total	205.0 MBtu	216.1 MBtu	238.4 MBtu

If the leaving air temperature of the DOAS is lowered, the energy use of the indoor cooling system can be also be reduced by decreasing the indoor cooling load. However, since the efficiency of DOAS is less than that of the indoor air conditioner, the total energy consumption is increased.

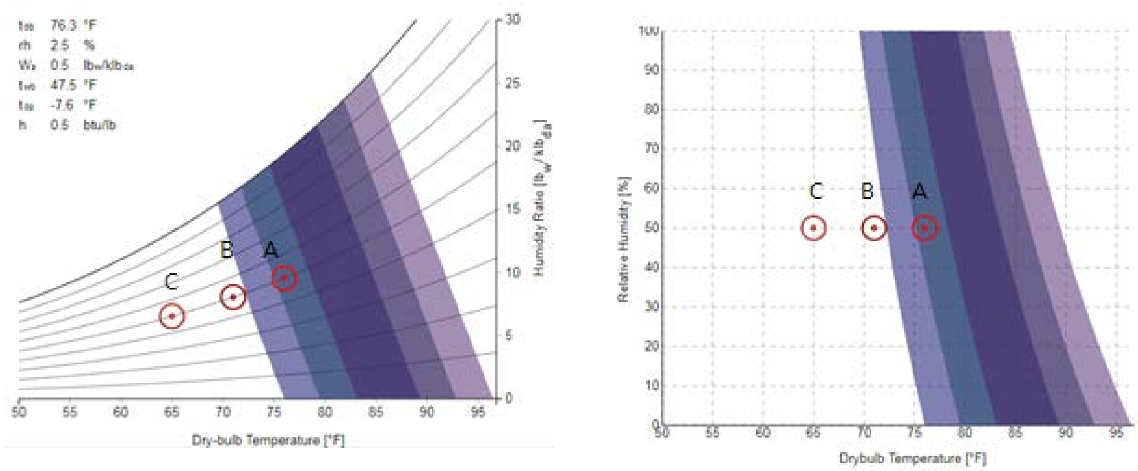
Indoor Thermal Comfort

To review effects on thermal comfort, a sample office space was designed and analyzed by the computational fluid dynamics (CFD) method as shown in Table 3. CFD simulated results of Predicted Mean Vote (PMV) are reported in the occupied zone at the height three (3) feet above ground level. The CFD analysis condition for each DOAS leaving air temperature is shown in Table 3.

Table 3: CFD Modeling Conditions.

Control Options	**Option A (DOAS LAT: Neutral)**	**Option B (DOAS LAT: Slightly Cold)**	**Option C (DOAS LAT: Cold)**
Building set point temperatures Cooling: 75°F	Leaving air temperature: 75°F Mean radiant temperature: 75°F Air speed: 20 fpm Humidity: 50% RH Metabolic rate: 1.2 met Clothing level: 0.5 clo	Leaving air temperature: 65°F Mean radiant temperature: 71.6°F Air speed: 20 fpm Humidity: 50% RH Metabolic rate: 1.2 met Clothing level: 0.5 clo	Leaving air temperature: 55°F Mean radiant temperature: 68°F Air speed: 20 fpm Humidity: 50% RH Metabolic rate: 1.2 met Clothing level: 0.5 clo

Table 4 shows computed results of thermal comfort levels using the three options. The expected PMV of "Neutral Air", Option A is -0.08, which is in accordance with ASHRAE Standard 55-2013. Occupants of Option A will experience moderate levels of thermal comfort. The thermal sensations for Option B and Option C are "Slightly cool" and "Cold", respectively. The operating energy of the primary HVAC system using Option B and Option C will be slightly reduced. The expected PMVs of the Option B and C are -0.87 and -1.74; these thermal comfort levels do not comply with ASHRAE Standard 55-2013.



(a) Psychrometric chart. (b) Temperature-humidity chart.

Figure 12: Indoor Thermal Comfort.

Table 4: Indoor Thermal Comfort (Cooling Result).

Control Options	**Option A (DOAS LAT: Neutral)**	**Option B (DOAS LAT: Slightly Cold)**	**Option C (DOAS LAT: Cold)**
PMV with Elevated Air	-0.08	-0.87	-1.74
PPD with Elevated Air	5%	21%	64%
Sensation	Neutral	Slightly Cool	Cold

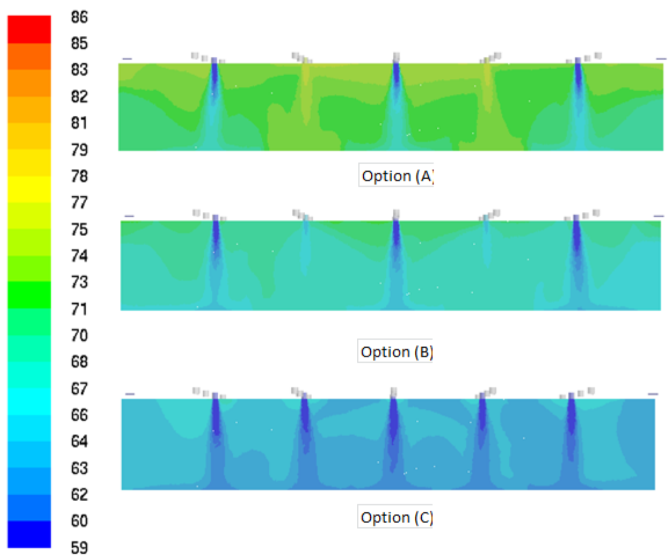


Figure 13: Indoor Thermal Comfort-CFD Analysis Result.

Modeling Approach

Overview

To model the baseline and proposed design, LG ACT used the IES VE 2021[7]. The IES Virtual Environment (IES VE) is an in-depth suite of building performance analysis tools. It assists in the design and operation of comfortable buildings that consume less energy. IES VE performs energy and thermal calculations on an hour-by-hour basis for a typical one-year period, resulting in an energy consumption model. To determine savings, the energy consumption was calculated using Leadership in Energy and Environmental Design (LEED[8]) baseline building requirements, except the HVAC systems. Because of a joint effort[9] between LG Electronics and IES, starting in 2019, the IES VE has been added to the LG VRF performance curves to model LG Multi V Air and Water VRF systems. If energy modeling engineers use IES VE, the performance of LG VRF systems can be accurately reflected in building modeling without additional work.

Baseline Building

The baseline building model followed LEED design guidelines, and used building material specifications defined by ASHRAE Standard 90.1-2013 for the envelope such as U-values for walls, roofs, floors, and windows (see Table 6). The conditioned areas followed ASHRAE Standard 90.1-2013, were served by VRF systems, and direct ventilation method supplied conditioned fresh air to each space. The building was assumed to be fully heated and cooled. Setup and setback schedules were implemented during unoccupied hours (nighttime) when the VRF system was set to maintain temperature and humidity requirements. See Table 7 for specification details.

- Baseline (1) - Primary Building HVAC: LG VRF Multi V + OA HVAC: Packaged DOAS.
- Baseline (2) - Primary Building HVAC: LG VRF Multi V + Packaged DOAS + ERV.

Proposed Buildings

The proposed building models followed LEED design guidelines, and applied VRF systems as the primary heating and cooling system. The proposed building also used identical building material specifications as defined by ASHRAE Standard 90.1-2013 for the envelope such as U-values for walls, roofs, floors, and windows. See Table 6. The proposed buildings applied split type DOAS, packaged DOAS, and packaged DOAS with ERV as the outdoor air conditioning system. See Table 8 for specification details.

- Proposed - Primary Building HVAC: LG VRF Multi V + Split Compact DOAS.

DOAS Case Study

The case study explored the implementation of a high efficient LG Multi V DOAS in a typical new construction office building. The study was conducted using a building model with the same physical properties, and with the same specifications, in eight different climates—Miami, FL (1A); Houston, TX (2A); Atlanta, GA (3A); Los Angeles, CA (3B); New York, NY (4A); Seattle, WA (4C); Chicago, IL (5A); and Madison, WI (6A).

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[7] https://www.iesve.com/ve2021.

[8] LEED®—an acronym for Leadership in Energy and Environmental Design™—is a registered trademark of the U.S. Green Building Council.

[9] https://www.iesve.com/software/download/release-notes/ve-2019/ies-ve-2019-fp-02-release-notes.pdf.

The building consisted of three (3) stories with a total area of conditioned space at 53,660 ft². The building's envelopes consisted of a mass wall with friction-fit insulation, and a roof with insulation entirely above a deck. The common spaces and offices were expected to operate from Monday through Friday (7am to 8pm) and Saturday (7am to 1pm), 71 hours per week.

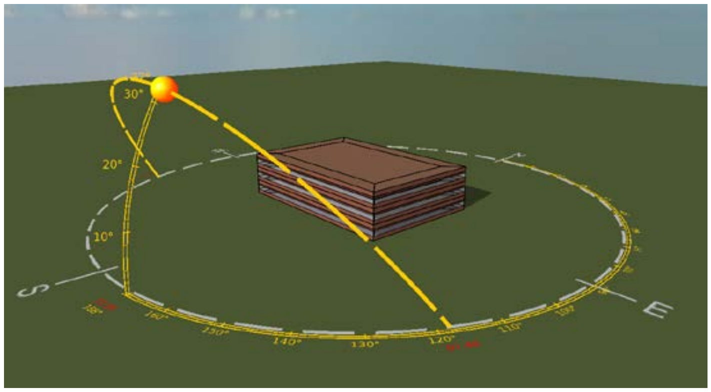


Figure 14: Model Building.

Table 5: Office Space Sizes, occupancy, and ventilation airflow.

Space Name	Size (ft²)	Design Occupancy (People)	Minimum Outdoor Ventilation Airflow (cfm)
1st Floor North	2,232.0	7.7	174.5
1st Floor West	1,413.0	4.9	110.5
1st Floor South	2,232.0	7.7	174.5
1st Floor East	1,413.0	4.9	110.5
1st Floor Interior	10,597.0	36.6	828.5
2nd Floor North	2,232.0	7.7	174.5
2nd Floor West	1,413.0	4.9	110.5
2nd Floor South	2,232.0	7.7	174.5
2nd Floor East	1,413.0	4.9	110.5
2nd Floor Interior	10,597.0	36.6	828.5
3rd Floor North	2,232.0	7.7	174.5
3rd Floor West	1,413.0	4.9	110.5
3rd Floor South	2,232.0	7.7	174.5
3rd Floor East	1,413.0	4.9	110.5
3rd Floor Interior	10,597.0	36.6	828.5
Total	53,660.9	185.4	4,195.3

Component Comparison

Several components were considered and analyzed in the building models:

- Modeled sizes and efficiencies (code minimum efficiencies)
- Building envelope
- Lighting system
- Mechanical system
- Domestic hot-water system

Baseline and Proposed Building Envelope

The model's building envelope characteristics followed the values stipulated by LEED, which adheres to ASHRAE Standard 90.1-2013:

Table 6: Building Envelope Characteristics.

Components		Locations (Climate Zones)							
		Miami, FL (1A)	**Houston, TX (2A)**	**Atlanta, GA (3A)**	**Los Angeles, CA (3B)**	**New York, NY (4A)**	**Seattle, WA (4C)**	**Chicago, IL (5A)**	**Madison, WI (6A)**
Windows: (36% of Wall Area)	Assembly U-factor	1.20	0.65	0.6	0.6	0.50	0.50	0.45	0.45
	SHGC	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40
Exterior Walls (Mass Wall Building)	Above Grade U-factor	0.58	0.151	0.123	0.123	0.104	0.104	0.09	0.08
	Below Grade	C-1.14	C-1.14	C-1.14	C-1.14	C-1.14	C-1.14	C-1.119	C-1.119
Roofs U-factor (Entirely Insulated)		0.063	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Floors U-factor		0.253	0.052	0.052	0.052	0.038	0.038	0.038	0.038
Opaque Doors U-factor		0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700
Interior Lighting		Average 0.82 W/ft²							
Occupancy		275 ft²/person							
Standard		ASHRAE 90.1-2013 ASHRAE 62.1-2013							

HVAC System

Baseline and proposed HVAC systems were as follows:

Table 7: DOAS and Cooling/Heating System Characteristics.

HVAC System		Baseline		Proposed[10]
		Baseline (1): VRF + LG Packaged DOAS	**Baseline (2): VRF + LG Packaged DOAS+ ERV**	**VRF + LG Split Compact DOAS**
Indoor Cooling/ Heating	DX-Cooling /Heat Pump	LG Multi V VRF, 15 EER/4.5 COP	LG Multi V VRF, 15 EER/4.5 COP	LG Multi V VRF, 15 EER/4.5 COP
	Air Handlers	Ducted Type VRF Indoor units (0.1W/cfm)	Ducted Type VRF Indoor units (0.1W/cfm)	Ducted Type VRF Indoor units (0.1W/cfm)
Outdoor Air Section (LAT: 75°F-Cooling, 70°F-Heating)		LG Packaged DOAS* AR-DR12-07A Cooling 105.4 (kBtu/h) Heating 200 (kBtu/h) 1,500 cfm 1 HP AR-DR12-12A Cooling 155.6 (kBtu/h) Heating 250 (kBtu/h) 2,250 cfm 1.5 HP AR-DR12-15A Cooling 202.9 (kBtu/h) Heating 300 (kBtu/h) 2,900 cfm 3 HP (ECM/Direct Drive) 1.5 ESP (in. wg)	LG Packaged DOAS* Wheel Type Energy recovery ventilator AR-DE12-05A Cooling 67 (kBtu/h) Heating 80 (kBtu/h) 1,700 cfm SA 1 HP /EA 1HP AR-DE12-07A Cooling 104 (kBtu/h) Heating 80 (kBtu/h) 2600 cfm SA 3 HP/EA 1HP AR-DE12-10A Cooling 126.6 (kBtu/h) Heating 120 (kBtu/h) 2950 cfm SA 5 HP / EA 1HP (ECM/Direct Drive)2.0ESP (in. wg) Energy recovery ventilator Sensible heat effectiveness: 68% Latent heat effectiveness 61% Motor power consumption:0.1kW	LG Split DOAS* ARND153DCR4 Cooling 120,000 (Btu/h) Heating 51,000 (Btu/h) 1,500 cfm 1 HP ARND203DCR4 Cooling 143,000 (Btu/h) Heating 59,900 (Btu/h) 2,000 cfm 1 HP ARND30UDBE4 Cooling 200,000 (Btu/h) Heating 135,000 (Btu/h) 3,000 cfm 10HP (BLDC /Direct Drive)1.5ESP (in. wg)
		DX cooling (9.4 EER) /Gas furnace (80%)	DX cooling (9.4 EER) /Gas furnace (80%)	Multi V Condensing unit Cooling:15 EER Heating: 4.5 COP

(*https://www.ahridirectory.org/ahridirectory/pages/vrfhp/defaultSearch.aspx.)

10 https://lghvac.com/commercial/product-type/?productTypeId=a2x44000003XR0s&iscommercial=true&class=Air%20Technologies.

Figure 15 shows a diagram of the VRF system and the DOAS.

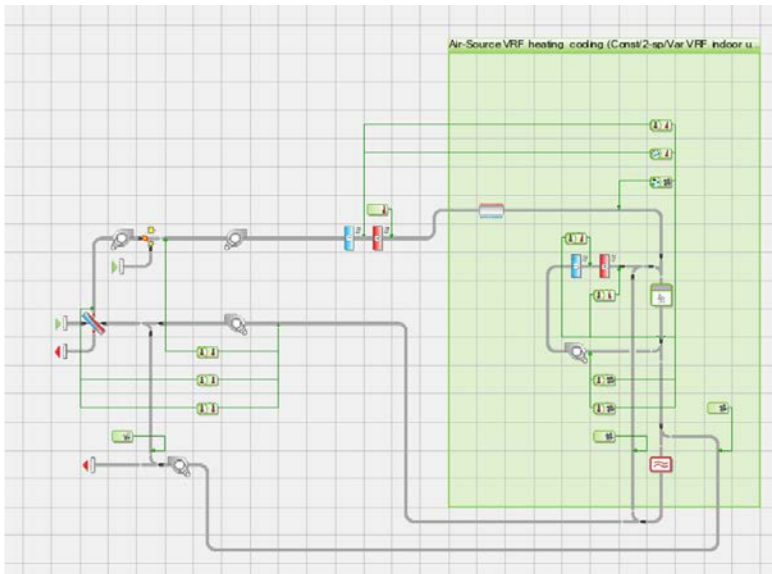


Figure 15: DOAS - VRF Outdoor and Indoor Units.

Ventilation

The ventilation or OA flow rate requirement for models concerning medium office buildings is adopted from ASHRAE Standard 62.1-2013. This study uses 5.0 cfm/person (ventilation coefficient Rp) and 0.06cfm/ft² (ventilation coefficient Ra).

Table 8: Proposed: Split Type DOAS: 1,500, 2,000, and 3,000 CFM.

	ARND153DCR4	ARND203DCR4	ARND30UDBE4
Total Cooling Capacity (Btu/h)	120,000	143,100	200,000
Moisture Removal Capacity (lb. / h)	37.2	51.5	105
Heating Capacity (Btu/h) (Main Coil)	51,000	59,900	135,000
Fan Motor (HP / W)	1 / 750	1 / 750	10
Airflow Rate (CFM)	1,000 – 1,500	1,000 – 2,000	3,000
External Static Pressure (in. w.g.)	2.0	1.5	2.0
Filter (factory supplied) - 2" MERV 13 filters (field supplied).	2" Merv 8 (25" x 20")	2" Merv 8 (25" x 20")	2" Merv 8 (2) 25”x25”

Figure 16:-Figure 18 show P-Q curves of the proposed DOAS.

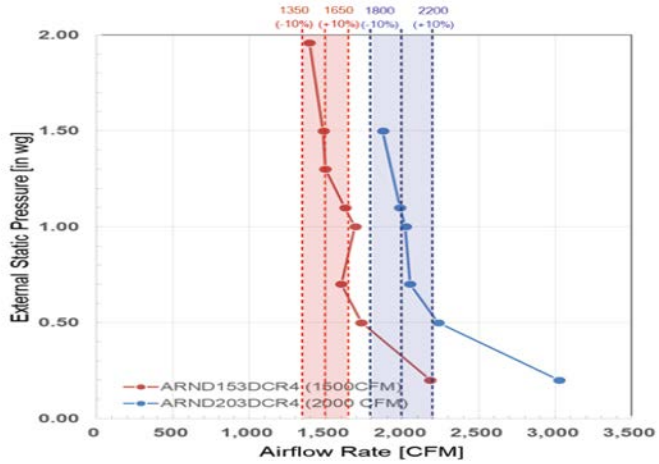


Figure 16: Proposed DOAS- ARND153DCR4 and ARND203DCR4 Airflow Rate Change by External Static Pressure.

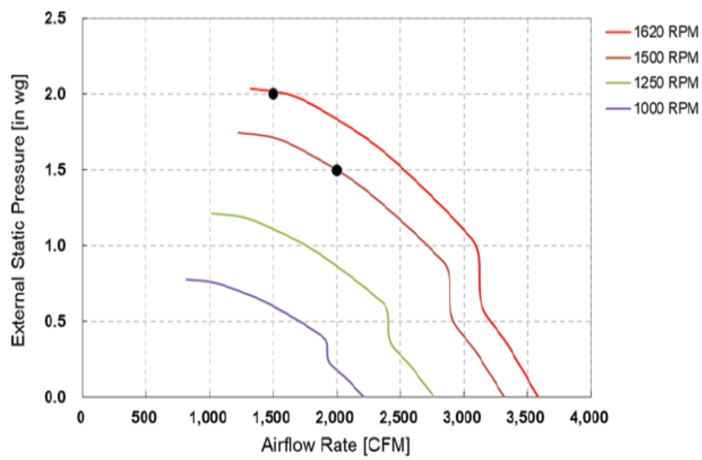


Figure 17: Proposed DOAS- ARND153DCR4 and ARND203DCR4 Airflow Rate Change by Static Pressure.

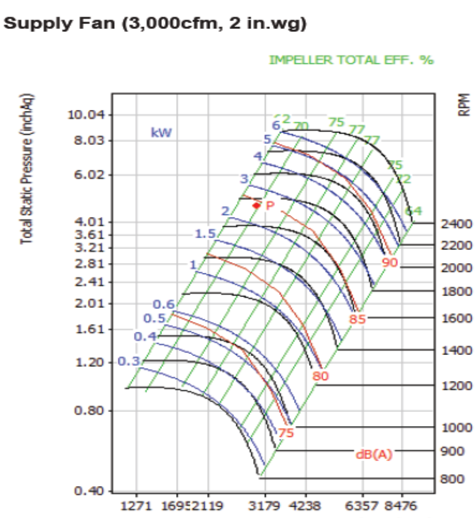


Figure 18: Proposed DOAS-ARND30UDBE4 Airflow Rate Change by Static Pressure.

Interior Lighting

Baseline and proposed interior lighting were as follows:

Table 9: Interior-Lighting Energy Characteristics.

	Baseline	Proposed	Notes
Interior Lighting	Lighting Power Density (Average: 0.82 W/ft²)	Same	ASHRAE 90.1-2013; Table 9.5.1: Lighting Power Densities Using the Building Area Method

Receptacle Load

Baseline and proposed receptacle equipment were as follows:

Table 10: Receptacle Load Energy Characteristics.

	Baseline	Proposed	Notes
Receptacle Load	0.75 W/ft²	Same	ASHRAE 90.1-2013; Table G3.1 Modeling Requirements for Calculating Proposed and Baseline Building Performance

Average Utility Rates Source

The study used the following sources for electrical and natural gas rates:

Table 11: Commercial Electrical and Natural Gas Rates (2022).

Energy Source	Miami, FL (1A)	Houston, TX (2A)	Atlanta, GA (3A)	Los Angeles, CA (3B)	New York, NY (4A)	Seattle, WA (4C)	Chicago, IL (5A)	Madison, WI (6A)
Electricity (Cents/kWh)[11]	10.97	8.51	11.28	19.30	16.21	9.55	10.92	11.45
Natural Gas ($/McF)[12]	12.01	7.52	8.71	10.78	7.88	9.76	7.84	6.74

11 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

12 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm .

Results

Overview

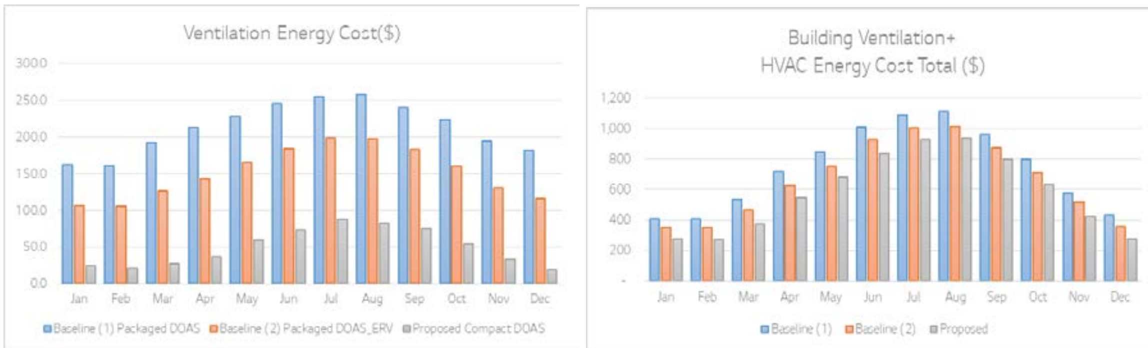
The energy simulation results at Table 12 for various climates showed the LG compact type DOAS had potential ventilation air conditioning system's average energy cost savings ranging from 66% to 72% when compared to the packaged type DOAS. These OA conditioning energy cost savings represent 20% to 27% of the total building energy savings. Integrating higher efficiency into the DOAS system with neutral air can be a good way to conserve energy throughout the building, and keep optimum comfort levels. Cold-temperature air by DOAS helps dehumidify the building space. With the help of the cold air, primary HVAC system equipment can be downsized to conserve energy; however, the design engineer should be aware that cold air drafts can cause thermal discomfort.

Table 12: Summary of LG Compact Type DOAS Ventilation Energy Cost Savings % and Total HVAC Energy Cost Savings %.[13]

Location (Climate Zone)	DOAS Energy Cost Savings (%)*		Building (DOAS + Indoor) HVAC Energy Cost Savings (%)*	
	Vs Packaged Type DOAS	Vs Packaged ERV Type DOAS	Vs Packaged Type DOAS	Vs Packaged ERV Type DOAS
Miami, FL (1A)	77%	67%	22%	12%
Houston, TX (2A)	77%	72%	29%	24%
Atlanta, GA (3A)	76%	67%	28%	23%
Los Angeles, CA (3B)	87%	84%	23%	19%
New York, NY (4A)	72%	66%	14%	14%
Seattle, WA (4C)	73%	68%	33%	25%
Chicago, IL (5A)	59%	48%	16%	11%
Madison, WI(6A)	59%	52%	13%	11%
Average	72%	66%	27%	20%

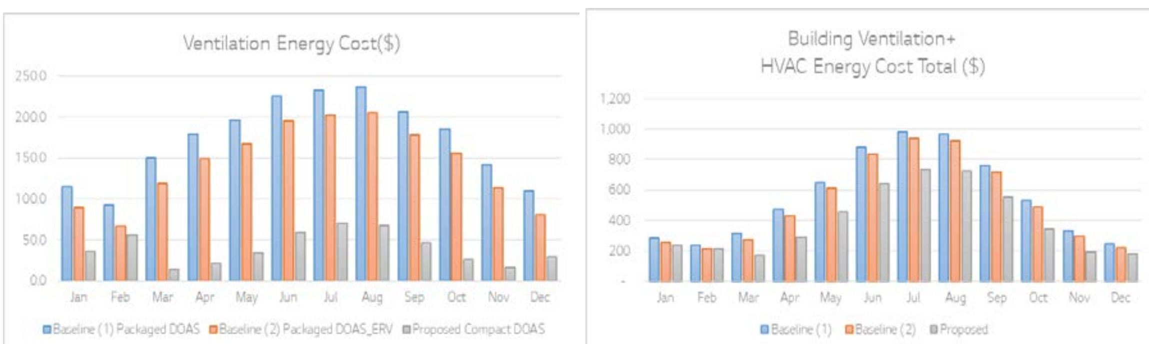
[13] **Legal Disclaimer:** The models described in this report are intended to demonstrate the potential cost-effectiveness of possible energy improvements for new facilities under the conditions as identified in the white paper. The choice of models was subject to the professional judgment of LG Electronics U.S.A., Inc., in accordance with industry standards. The models and conclusions of this report do not guarantee actual energy costs or savings.

The building energy usages are combined into electricity and gas categories. Figure 19 through Figure 26 show the system Ventilation Air Conditioning Energy Cost for electricity and gas for all the simulated locations.



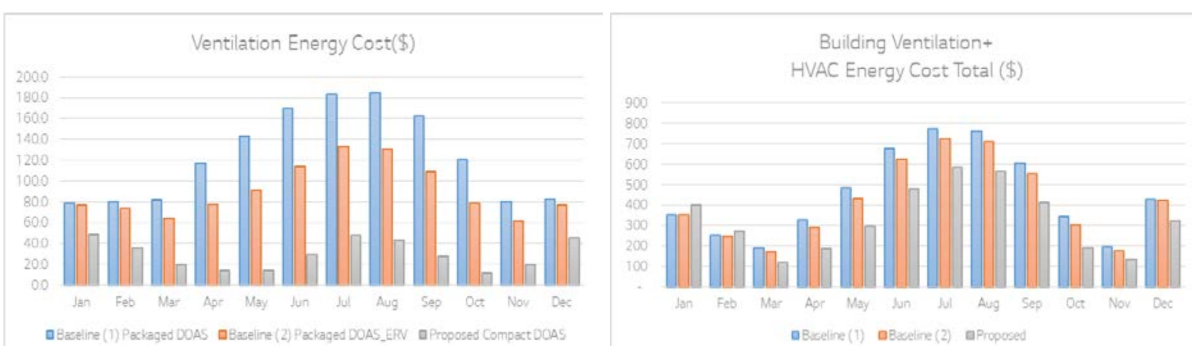
(a) Ventilation (b) HVAC Total: Ventilation + Indoor

Figure 19: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Miami, FL.



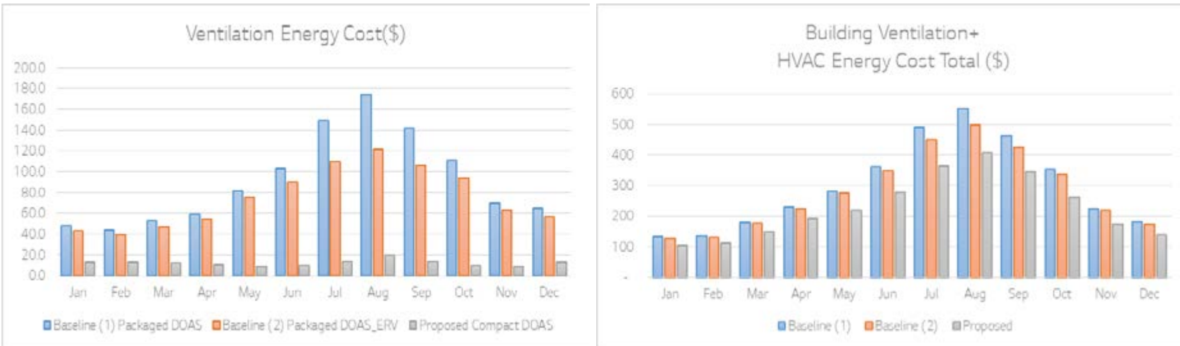
(a) Ventilation (b) HVAC Total: Ventilation + Indoor

Figure 20: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Houston, TX.



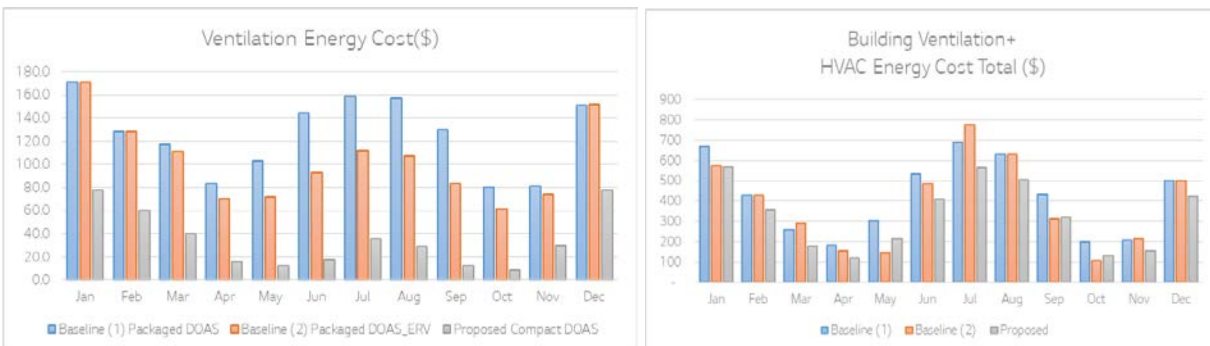
(a) Ventilation (b) HVAC Total: Ventilation + Indoor

Figure 21: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Atlanta, GA.



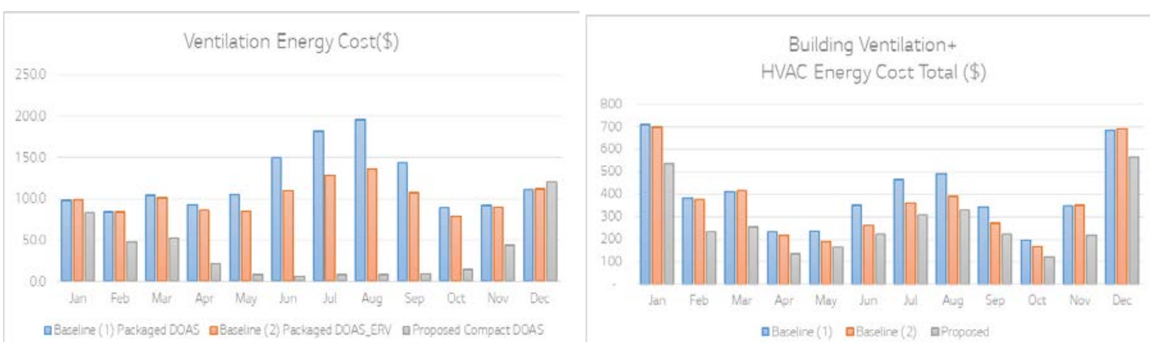
(a) Ventilation (b) HVAC Total: Ventilation + Indoor

Figure 22: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Los Angeles, CA.



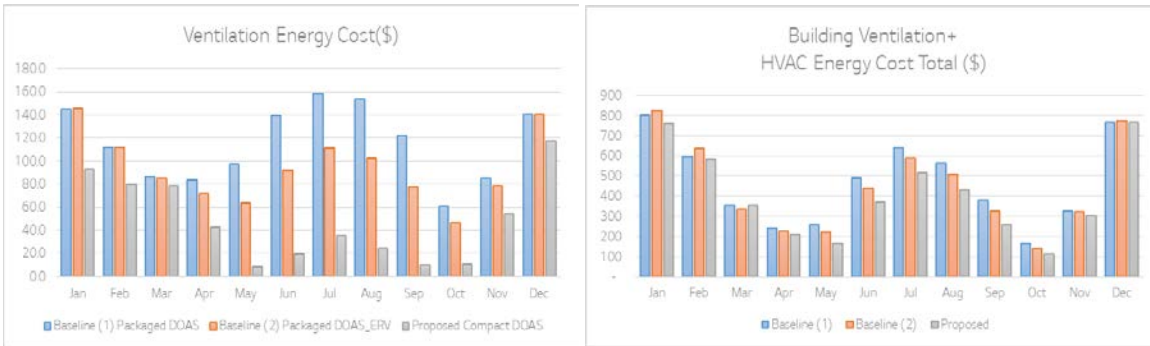
(a) Ventilation (b) HVAC Total: Ventilation + Indoor

Figure 23: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – New York, NY.



(a) Ventilation (b) HVAC Total: Ventilation + Indoor

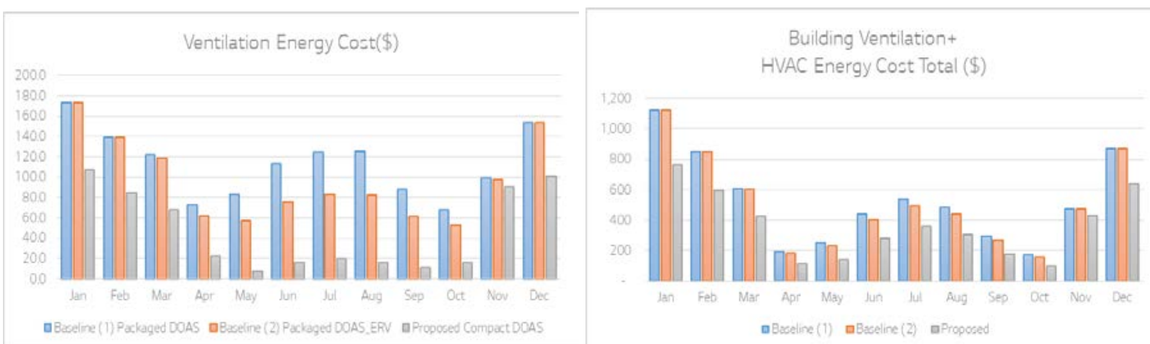
Figure 24: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Seattle, WA.



(a) Ventilation

(b) HVAC Total: Ventilation + Indoor

Figure 25: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Chicago, IL.



(a) Ventilation

(b) HVAC Total: Ventilation + Indoor

Figure 26: Ventilation Air Conditioning Energy Cost ($) and HVAC Total Energy Cost ($) – Madison, WI.

Miami Results (1A)

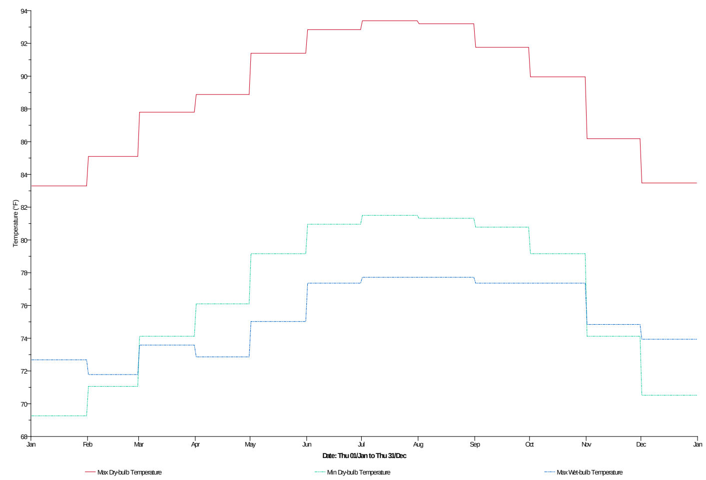


Figure 27: Design Day - Miami.

Energy consumption by end use for the Miami location (Climate Zone 1A) was as follows:

Table 13: Annual Ventilation Air Conditioning Energy Consumption - Miami.

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	3.0	1,320.9	84.4	35.5	2.9	848.7	54.2	47.5	17.6	171.4	10.8	23.7
Feb	1.3	1,328.8	84.7	34.0	1.3	849.0	54.2	45.4	5.3	157.7	10.0	22.9
Mar	1.1	1,601.3	102.3	39.9	1.1	1,027.2	65.6	53.3	4.4	206.0	13.2	26.7
Apr	0.0	1,788.9	114.3	38.4	0.0	1,178.4	75.3	51.3	0.0	292.8	18.8	25.5
May	0.0	1,912.6	122.2	36.9	0.0	1,368.1	87.3	49.2	0.0	483.6	30.8	24.6
Jun	0.0	2,062.9	131.6	38.4	0.0	1,525.7	97.3	51.3	0.0	599.9	38.4	25.5
Jul	0.0	2,147.9	137.2	37.5	0.0	1,653.8	105.5	50.1	0.0	723.9	46.3	25.2
Aug	0.0	2,171.7	138.6	39.0	0.0	1,638.9	104.6	52.2	0.0	685.5	43.7	26.1
Sep	0.0	,2023.9	129.2	36.9	0.0	1,519.3	97.0	49.2	0.0	625.1	39.9	24.6
Oct	0.0	1,875.7	119.9	36.9	0.0	1,322.6	84.4	49.2	0.0	444.9	28.4	24.6
Nov	0.0	1,628.3	104.0	35.5	0.0	1,072.9	68.6	47.2	0.3	265.5	17.0	23.7
Dec	0.5	1,513.1	96.7	38.7	0.5	939.6	60.1	51.6	2.1	132.2	8.5	25.8
Total	6.0	21,376.0	1,364.5	447.8	5.8	14,944.6	953.9	597.0	29.6	4,788.5	305.7	298.6

Because outdoor air temperature and humidity conditions vary depending on weather conditions, the ventilation system's operating conditions require partial load performance in most of the time compared to peak load. It is important, therefore, to select a DOAS system with excellent partial load efficiency to save energy such as a variable speed air conditioner or heat pump.

Figure 28: Ventilation Air Conditioning Energy (MBtu) - Miami.

The average ventilation energy cost savings by proposed system for the Miami location (Climate Zone 1A) are 77% over the baseline (1) and 67% over the baseline (2).

Table 14: Annual Ventilation Air Conditioning Energy Cost Comparisons - Miami: 10.97 (Cents/kWh)[14], 7.84 12.01 ($/McF)[15].

	Baseline						Proposed				
	(1) Packaged DOAS			(2) Packaged DOAS_ERV			Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	3.54	158.0	161.6	3.47	104.3	107.7	0	24.5	24.5	85%	77%
Feb	1.60	158.8	160.4	1.55	104.1	105.6	0	21.5	21.5	87%	80%
Mar	1.31	191.3	192.6	1.26	125.7	127.0	0	27.5	27.5	86%	78%
Apr	0.00	213.0	213.0	0.00	143.2	143.2	0	37.0	37.0	83%	74%
May	0.00	227.3	227.3	0.00	165.1	165.1	0	59.1	59.1	74%	64%
Jun	0.00	245.0	245.0	0.00	183.7	183.7	0	72.8	72.8	70%	60%
Jul	0.00	254.8	254.8	0.00	198.5	198.5	0	87.3	87.3	66%	56%
Aug	0.00	257.7	257.7	0.00	197.0	197.0	0	82.9	82.9	68%	58%
Sep	0.00	240.3	240.3	0.00	182.7	182.7	0	75.6	75.6	69%	59%
Oct	0.00	223.0	223.0	0.00	159.8	159.8	0	54.6	54.6	76%	66%
Nov	0.05	193.9	194.0	0.05	130.4	130.4	0	33.6	33.6	83%	74%
Dec	0.65	180.8	181.5	0.62	115.3	115.9	0	18.5	18.5	90%	84%
Total	7.15	2,543.8	2,550.9	6.95	1,809.6	1,816.5	0	594.8	594.8	77%	67%

14 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

15 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Miami location (Climate Zone 1A) are 22% over baseline (1) and 12% over baseline (2).

Table 15: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Miami: 10.97 (Cents/kWh)[16], 12.01 ($/McF)[17].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	406	353	273	33%	22%
Feb	407	350	272	33%	22%
Mar	533	466	372	30%	20%
Apr	716	626	543	24%	13%
May	849	751	683	19%	9%
Jun	1,008	930	837	17%	10%
Jul	1,094	1,007	928	15%	8%
Aug	1,112	1,016	939	16%	8%
Sep	963	877	801	17%	9%
Oct	799	711	634	21%	11%
Nov	576	516	420	27%	19%
Dec	435	358	277	36%	23%
Total	8,899	7,960	6,980	22%	12%

[16] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

[17] https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Houston Results (2A)

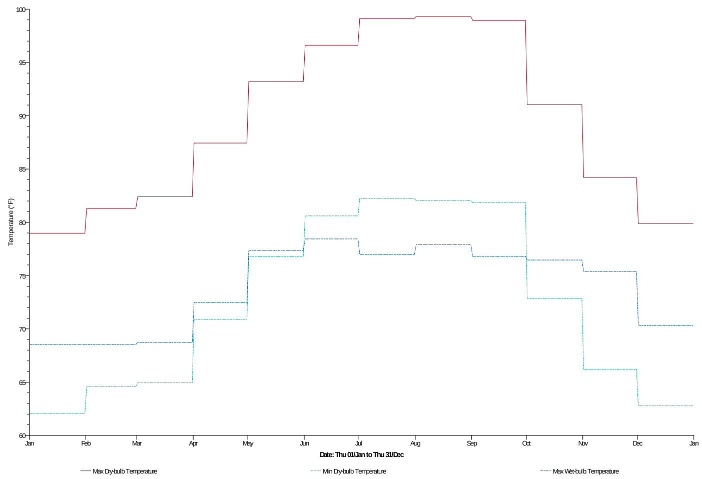


Figure 29: Design Day - Houston.

Energy consumption by end use for the Houston location (Climate Zone 2A) was as follows:

Table 16: Annual Ventilation Air Conditioning Energy Consumption - Houston.

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	62.3	698.7	44.5	55.1	29.5	430.8	27.5	73.3	344.1	56.3	3.5	23.7
Feb	67.1	413.5	26.4	53.0	33.3	252.6	16.1	70.6	622.5	22.0	1.5	22.9
Mar	49.6	1,189.0	75.9	63.3	8.6	742.1	47.5	84.4	46.0	92.0	5.9	26.7
Apr	41.2	1,586.7	101.4	60.4	0.9	1,025.7	65.4	80.6	4.1	204.3	13.2	25.8
May	38.5	1,796.2	114.6	57.1	0.0	1,230.9	78.5	76.2	0.0	359.6	22.9	24.6
Jun	40.1	2,107.5	134.5	60.1	0.0	1,575.5	100.5	80.0	0.0	637.1	40.7	25.5
Jul	39.3	2,186.6	139.5	58.6	0.0	1,699.5	108.4	78.0	0.0	755.0	48.1	25.2
Aug	40.8	2,215.3	141.6	61.0	0.0	1,697.2	108.4	81.2	0.0	721.8	46.0	26.1
Sep	38.5	1,911.1	121.9	57.7	0.0	1,376.8	87.9	76.8	0.0	487.4	31.1	24.6
Oct	38.8	1,668.7	106.4	57.1	0.3	1,109.0	70.9	76.5	1.2	269.6	17.3	24.6
Nov	42.3	1,161.4	74.1	55.7	5.1	738.2	47.2	74.4	39.6	119.6	7.6	23.7
Dec	64.5	623.9	39.9	60.7	26.0	395.1	25.2	80.9	257.6	62.7	4.1	25.8
Total	563.0	17,558.5	1,120.7	699.6	103.6	12,273.8	783.4	932.8	1,315.0	3,787.4	241.8	298.9

Because outdoor air temperature and humidity conditions vary depending on weather conditions, the ventilation system's operating conditions require partial load performance most of the time compared to peak load. It is important, therefore,to select a DOAS system with excellent partial load efficiency to save energy such as a variable speed air conditioner or heat pump.

Figure 30: Ventilation Air Conditioning Energy (MBtu) - Houston.

The average DOAS Energy cost savings by proposed system for the Houston location (Climate Zone 2A) are 77% over the baseline (1) and 72% over the baseline (2).

Table 17: Annual Ventilation Air Conditioning Energy Cost Comparisons - Houston: 8.51 (Cents/kWh)[18], 7.52 ($/McF)[19].

	Baseline						Proposed				
	(1) Packaged DOAS			(2) Packaged DOAS_ERV			Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	46.85	67.9	114.8	22.15	45.2	67.4	0	36.4	36.4	68%	59%
Feb	50.47	41.9	92.4	25.00	28.9	53.9	0	56.9	56.9	38%	15%
Mar	37.33	113.0	150.4	6.50	74.4	80.9	0	14.5	14.5	90%	88%
Apr	30.96	148.8	179.8	0.69	99.7	100.4	0	21.0	21.0	88%	86%
May	28.94	167.5	196.4	0.02	117.9	117.9	0	34.6	34.6	82%	79%
Jun	30.13	195.9	226.0	0.00	149.4	149.4	0	59.9	59.9	74%	69%
Jul	29.52	202.9	232.5	0.00	160.5	160.5	0	70.5	70.5	70%	65%
Aug	30.69	205.8	236.4	0.00	160.6	160.6	0	67.6	67.6	71%	67%
Sep	28.97	177.9	206.9	0.00	131.2	131.2	0	46.2	46.2	78%	74%
Oct	29.18	155.9	185.1	0.19	106.9	107.1	0	26.6	26.6	86%	83%
Nov	31.83	109.9	141.7	3.83	73.2	77.0	0	16.2	16.2	89%	86%
Dec	48.47	61.7	110.1	19.53	42.6	62.2	0	29.8	29.8	73%	63%
Total	423.35	1,649.1	2,072.5	77.89	1,190.6	1,268.4	0	480.2	480.2	77%	72%

18 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
19 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Houston location (Climate Zone 2A) are 29% over baseline (1) and 24% over baseline (2).

Table 18: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Houston: 8.51 (Cents/kWh)[20], 7.52 ($/McF)[21].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	286	260	235	18%	10%
Feb	259	239	216	16%	9%
Mar	316	275	171	46%	38%
Apr	472	430	287	39%	33%
May	652	611	453	30%	26%
Jun	877	835	642	27%	23%
Jul	981	939	736	25%	22%
Aug	968	924	722	25%	22%
Sep	760	719	551	27%	23%
Oct	529	488	345	35%	29%
Nov	332	294	192	42%	35%
Dec	249	218	180	28%	17%
Total	6,682	6,232	4,731	29%	24%

[20] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

[21] https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Atlanta Results (3A)

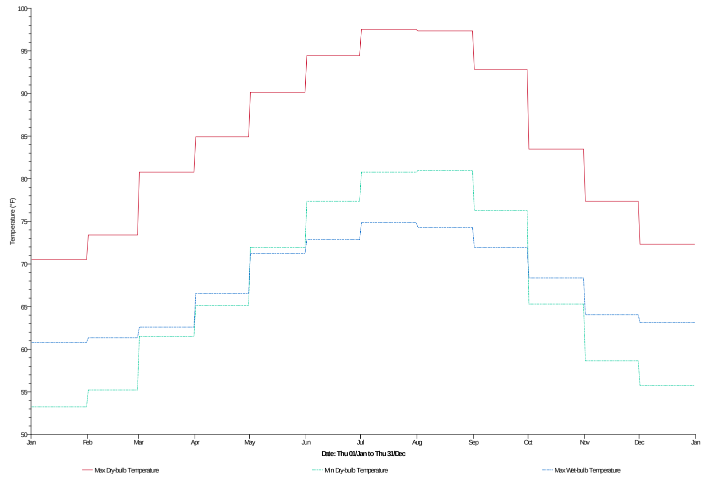


Figure 31: Design Day - Atlanta.

Energy consumption by end use for the Atlanta location (Climate Zone 3A) was as follows:

Table 19: Annual Ventilation Air Conditioning Energy Consumption - Atlanta.

	Baseline								**Proposed**			
	(1) Packaged DOAS				**(2) Packaged DOAS_ERV**				**Compact DOAS**			
	Heating	**Cooling**	**Heat Rejection**	**Fans**	**Heating**	**Cooling**	**Heat Rejection**	**Fans**	**Heating**	**Cooling**	**Heat Rejection**	**Fans**
	(Therm)	**(kWh)**	**(kWh)**	**(kWh)**	**(Therm)**	**(kWh)**	**(kWh)**	**(kWh)**	**(kWh)**	**(kWh)**	**(kWh)**	**(kWh)**
Jan	62.0	64.2	4.1	35.5	61.5	39.6	2.6	47.5	539.8	0.3	0.0	23.7
Feb	52.2	202.2	12.9	34.0	51.8	123.1	7.9	45.4	389.8	2.3	0.3	22.9
Mar	28.5	497.9	31.7	40.2	28.1	300.7	19.0	53.6	191.7	10.0	0.6	27.0
Apr	8.6	1,120.4	71.5	38.7	8.5	686.1	43.7	51.6	65.1	64.5	4.1	25.8
May	0.5	1,507.3	96.1	36.9	0.4	934.3	59.5	49.2	1.8	124.0	7.9	24.6
Jun	0.0	1,790.1	114.3	38.4	0.0	1,184.3	75.6	51.3	0.0	292.8	18.8	25.5
Jul	0.0	1,946.0	124.3	37.8	0.0	1,390.9	88.8	50.1	0.0	491.2	31.4	25.2
Aug	0.0	1,954.8	124.8	39.3	0.0	1,363.1	87.0	52.2	0.0	439.3	28.1	26.1
Sep	0.0	1,716.8	109.6	36.9	0.0	1,131.5	72.1	49.2	0.0	278.1	17.9	24.6
Oct	5.0	1,204.2	76.8	36.9	4.9	739.7	47.2	49.5	36.0	69.5	4.4	24.6
Nov	25.2	527.8	33.7	35.8	24.9	318.6	20.2	47.8	196.4	8.8	0.6	23.7
Dec	55.7	180.2	11.4	38.7	55.3	111.1	7.0	51.6	499.7	1.8	0.0	25.8
Total	237.6	12,712.0	811.5	449.3	235.4	8,323.2	531.3	599.0	1,920.2	1,782.5	113.7	299.5

Because outdoor air temperature and humidity conditions vary depending on weather conditions, the ventilation system's operating conditions require partial load performance most of the time compared to peak load. It is important, therefore, to select a DOAS system with excellent partial load efficiency to save energy such as a variable speed air conditioner or heat pump.

Figure 32: Ventilation Air Conditioning Energy (MBtu) - Atlanta.

The average DOAS Energy cost savings by proposed system for the Atlanta location (Climate Zone 3A) are 76% over the baseline (1) and 67% over the baseline (2).

Table 20: Annual Ventilation Air Conditioning Energy Cost Comparisons - Atlanta:.11.28 (Cents/kWh)[22], 8.71 ($/McF)[23].

	Baseline						Proposed				
	(1) Packaged DOAS			(2) Packaged DOAS_ERV			Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	69.9	9.0	79.0	69.39	7.8	77.2	0	49.1	49.1	38%	36%
Feb	58.9	21.7	80.6	58.46	15.4	73.8	0	36.2	36.2	55%	51%
Mar	32.1	49.6	81.7	31.66	32.5	64.2	0	20.0	20.0	76%	69%
Apr	9.7	107.2	116.9	9.57	68.1	77.6	0	13.9	13.9	88%	82%
May	0.5	142.9	143.4	0.49	90.8	91.3	0	13.8	13.8	90%	85%
Jun	0.0	169.2	169.2	0.00	114.2	114.2	0	29.4	29.4	83%	74%
Jul	0.0	183.6	183.6	0.00	133.2	133.2	0	47.7	47.7	74%	64%
Aug	0.0	184.6	184.6	0.00	130.8	130.8	0	43.0	43.0	77%	67%
Sep	0.0	162.3	162.3	0.00	109.1	109.1	0	27.9	27.9	83%	74%
Oct	5.6	114.8	120.4	5.49	72.9	78.3	0	11.7	11.7	90%	85%
Nov	28.5	52.0	80.5	28.11	33.7	61.8	0	20.0	20.0	75%	68%
Dec	62.8	20.1	82.9	62.32	14.8	77.1	0	45.9	45.9	45%	40%
Total	268.1	1,217.0	1,485.1	265.50	823.4	1,088.9	0	358.5	358.5	76%	67%

22 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

23 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Atlanta location (Climate Zone 3A) are 28% over baseline (1) and 23% over baseline (2).

Table 21: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Atlanta:.11.28 (Cents/kWh)[24], 8.71 ($/McF)[25].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	428	429	402	6%	6%
Feb	304	299	271	11%	10%
Mar	191	172	117	39%	32%
Apr	330	290	186	44%	36%
May	484	431	297	39%	31%
Jun	679	624	480	29%	23%
Jul	776	727	587	24%	19%
Aug	764	712	568	26%	20%
Sep	605	552	413	32%	25%
Oct	345	302	192	44%	37%
Nov	194	174	134	31%	23%
Dec	430	425	325	24%	24%
Total	5,528	5,138	3,972	28%	23%

[24] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
[25] https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Los Angeles Results (3B)

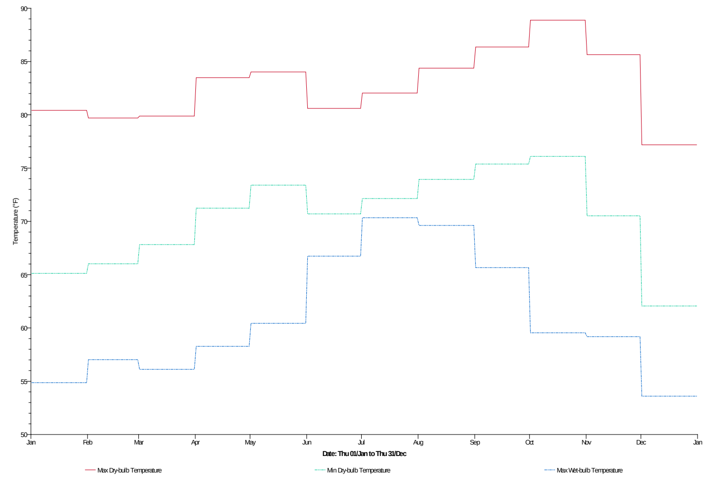


Figure 33: Design Day - Los Angeles.

Energy consumption by end use for the Los Angeles location (Climate Zone 3B) was as follows:

Table 22: Annual Ventilation Air Conditioning Energy Consumption - Los Angeles.

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	8.2	242.4	15.5	35.5	7.9	193.4	12.3	47.5	83.8	10.6	0.6	23.7
Feb	8.1	212.2	13.5	34.3	7.8	171.2	10.8	45.7	85.0	10.0	0.6	22.9
Mar	3.4	361.6	23.2	40.2	3.2	308.6	19.6	53.6	69.2	12.6	0.9	26.7
Apr	2.2	440.2	28.1	38.7	2.1	387.4	24.6	51.6	51.9	17.9	1.2	25.8
May	0.2	674.1	43.1	36.9	0.1	608.7	39.0	49.5	22.0	33.7	2.1	24.6
Jun	0.0	865.1	55.1	38.4	0.0	738.0	47.2	51.3	12.9	49.2	3.2	25.8
Jul	0.0	1,266.9	80.9	37.8	0.0	908.5	58.0	50.1	2.1	95.0	6.2	25.2
Aug	0.0	1,485.0	94.7	39.3	0.0	1,014.3	64.8	52.2	1.5	145.9	9.4	26.1
Sep	0.0	1,200.4	76.5	36.9	0.0	882.4	56.3	49.2	1.8	94.1	5.9	24.6
Oct	0.2	931.4	59.5	36.9	0.2	773.1	49.2	49.2	7.6	54.5	3.5	24.6
Nov	2.2	537.2	34.3	35.8	2.2	472.7	30.2	47.5	37.5	23.4	1.5	23.7
Dec	6.4	424.4	27.0	38.7	6.2	345.2	22.0	51.6	74.7	16.4	1.2	25.8
Total	30.9	8,640.9	551.6	449.6	29.7	6,803.6	434.3	599.3	449.9	563.0	35.8	299.5

Because outdoor air temperature and humidity conditions vary depending on weather conditions, the ventilation system's operating conditions require partial load performance most of the time compared to peak load. It is important, therefore, to select a DOAS system with excellent partial load efficiency to save energy such as a variable speed air conditioner or heat pump.

Figure 34: Ventilation Air Conditioning Energy (MBtu) - Los Angeles.

The average DOAS Energy cost savings by proposed system for the Los Angeles location (Climate Zone 3B) are 87% over the baseline (1) and 84% over the baseline (2).

Table 23: Annual Ventilation Air Conditioning Energy Cost Comparisons - Los Angeles: 19.30 (Cents/kWh)[26], 10.78 ($/McF)[27].

	Baseline						Proposed				
	(1) Packaged DOAS			(2) Packaged DOAS_ERV			Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	15.8	31.6	47.5	15.30	27.3	42.6	0	12.8	12.8	73%	70%
Feb	15.6	28.0	43.6	15.07	24.5	39.6	0	12.8	12.8	71%	68%
Mar	6.5	45.8	52.3	6.23	41.2	47.4	0	11.8	11.8	77%	75%
Apr	4.3	54.7	58.9	4.01	50.0	54.0	0	10.4	10.4	82%	81%
May	0.3	81.3	81.6	0.27	75.2	75.4	0	8.9	8.9	89%	88%
Jun	0.0	103.3	103.3	0.00	90.2	90.2	0	9.8	9.8	90%	89%
Jul	0.0	149.4	149.4	0.00	109.6	109.6	0	13.8	13.8	91%	87%
Aug	0.0	174.5	174.5	0.00	121.9	121.9	0	19.7	19.7	89%	84%
Sep	0.0	141.6	141.6	0.00	106.5	106.5	0	13.6	13.6	90%	87%
Oct	0.3	110.8	111.1	0.29	94.0	94.2	0	9.7	9.7	91%	90%
Nov	4.3	65.5	69.8	4.15	59.3	63.5	0	9.3	9.3	87%	85%
Dec	12.4	52.8	65.2	11.97	45.1	57.1	0	12.7	12.7	80%	78%
Total	59.5	1,039.4	1,099.0	57.30	844.9	902.2	0	145.3	145.3	87%	84%

26 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
27 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Los Angeles location (Climate Zone 3B) are 23% over baseline (1) and 19% over baseline (2).

Table 24: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Los Angeles: 19.30 (Cents/kWh)[28], 10.78 ($/McF)[29].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	133	128	103	23%	20%
Feb	135	131	112	17%	15%
Mar	180	175	149	17%	15%
Apr	230	225	192	17%	15%
May	282	276	220	22%	20%
Jun	360	347	278	23%	20%
Jul	489	449	364	26%	19%
Aug	551	498	407	26%	18%
Sep	462	427	344	26%	19%
Oct	354	337	263	26%	22%
Nov	225	219	174	22%	20%
Dec	182	174	138	24%	21%
Total	3,583	3,386	2,743	23%	19%

28 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

29 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

New York Results (4A)

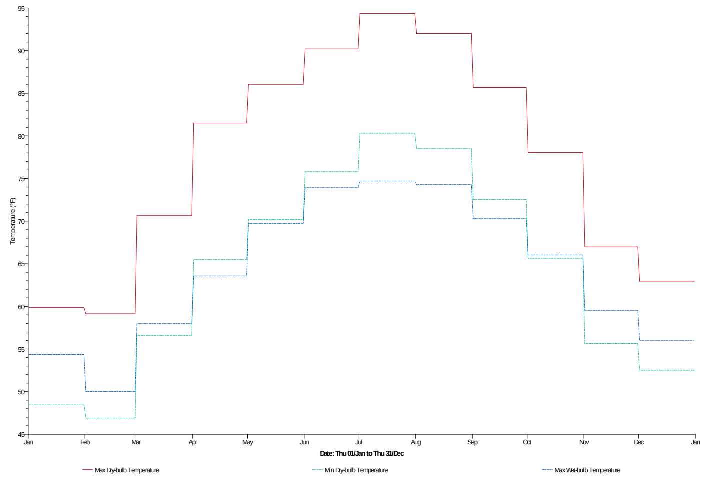


Figure 35: Design Day - New York.

Energy consumption by end use for the New York location (Climate Zone 4A) was as follows:

Table 25: Annual Ventilation Air Conditioning Energy Consumption - New York.

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	103.6	0.0	0.0	35.5	103.1	0.0	0.0	47.2	961.9	0.0	0.0	23.7
Feb	77.2	2.6	0.3	34.0	76.7	1.8	0.0	45.4	739.4	0.0	0.0	22.6
Mar	59.4	213.1	13.5	40.2	58.9	128.7	8.2	53.3	473.6	6.4	0.3	26.7
Apr	27.7	417.3	26.7	38.7	27.3	260.0	16.7	51.6	150.1	23.4	1.5	25.8
May	8.0	1,040.4	66.5	36.9	7.8	655.6	41.9	49.2	30.8	92.3	5.9	24.6
Jun	0.0	1,679.9	107.3	38.4	0.0	1,056.5	67.4	51.3	0.0	178.5	11.4	25.5
Jul	0.0	1,861.0	118.7	37.5	0.0	1,285.7	82.1	50.1	0.0	396.5	25.2	25.2
Aug	0.0	1,836.7	117.2	39.0	0.0	1,228.6	78.5	52.2	0.0	316.2	20.2	26.1
Sep	0.5	1,500.8	95.8	36.9	0.5	934.6	59.8	49.2	2.1	124.3	7.9	24.6
Oct	17.7	585.0	37.2	36.9	17.3	355.5	22.6	49.5	72.7	15.2	0.9	24.6
Nov	35.9	242.4	15.5	35.8	35.5	149.5	9.7	47.5	349.6	1.2	0.0	23.7
Dec	91.2	0.0	0.0	38.4	90.7	0.0	0.0	51.3	952.8	0.0	0.0	25.8
Total	421.2	9,379.2	598.7	448.4	417.8	6,056.3	386.6	597.9	3,732.8	1,153.8	73.6	298.9

Figure 36: Ventilation Air Conditioning Energy (MBtu) - New York.

The average DOAS Energy cost savings by proposed system for the New York location (Climate Zone 4A) are 72% over the baseline (1) and 66% over the baseline (2).

Table 26: Annual Ventilation Air Conditioning Energy Cost Comparisons - New York: 16.21 (Cents/kWh)[30], 7.88 ($/McF)[31].

	Baseline						**Proposed**				
	(1) Packaged DOAS			**(2) Packaged DOAS_ERV**			**Compact DOAS**			**Saving (%) by Compact DOAS over**	
	Gas ($)	**Electric ($)**	**Total ($)**	**Gas ($)**	**Electric ($)**	**Total ($)**	**Gas ($)**	**Electric ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	168.0	2.8	170.8	167.16	3.7	170.9	0	77.7	77.7	55%	55%
Feb	125.1	2.9	128.1	124.38	3.7	128.1	0	60.0	60.0	15%	53%
Mar	96.3	21.0	117.3	95.53	15.0	110.5	0	40.0	40.0	88%	64%
Apr	44.9	38.0	83.0	44.30	25.9	70.2	0	15.8	15.8	86%	77%
May	12.9	90.1	103.0	12.60	58.8	71.4	0	12.1	12.1	79%	83%
Jun	0.0	143.9	143.9	0.00	92.6	92.6	0	17.0	17.0	69%	82%
Jul	0.0	159.0	159.0	0.00	111.7	111.7	0	35.2	35.2	65%	68%
Aug	0.0	157.0	157.0	0.00	107.1	107.1	0	28.6	28.6	67%	73%
Sep	0.8	128.7	129.5	0.76	82.2	83.0	0	12.5	12.5	74%	85%
Oct	28.6	51.9	80.5	28.09	33.7	61.8	0	8.9	8.9	83%	86%
Nov	58.1	23.1	81.3	57.48	16.3	73.8	0	29.5	29.5	86%	60%
Dec	147.9	3.0	150.9	147.01	4.0	151.0	0	77.1	77.1	63%	49%
Total	682.7	821.6	1,504.3	677.29	554.8	1,232.1	0	414.4	414.4	72%	66%

30 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
31 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the New York location (Climate Zone 4A) are 23% over baseline (1) and 14% over baseline (2).

Table 27: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - New York: 16.21 (Cents/kWh)[32], 7.88 ($/McF)[33].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	669	574	570	15%	1%
Feb	427	426	356	17%	16%
Mar	257	292	180	30%	38%
Apr	184	202	119	35%	41%
May	309	217	214	31%	1%
Jun	532	439	408	23%	7%
Jul	688	590	567	18%	4%
Aug	629	627	503	20%	20%
Sep	433	319	310	26%	3%
Oct	198	177	129	35%	27%
Nov	275	237	154	44%	35%
Dec	502	503	425	15%	16%
Total	5,105	4,595	3,945	23%	14%

[32] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
[33] https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Seattle Results (4C)

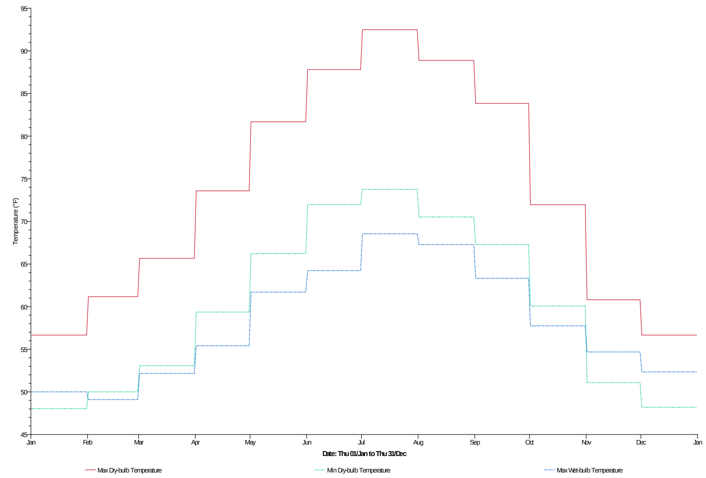


Figure 37: Design Day - Seattle.

Energy consumption by end use for the Seattle location (Climate Zone 4C) was as follows:

Table 28: Annual Ventilation Air Conditioning Energy Consumption - Seattle.

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	99.5	0.0	0.0	35.5	99.0	0.0	0.0	47.2	826.2	0.0	0.0	23.7
Feb	83.8	6.2	0.3	34.0	83.3	3.5	0.3	45.4	467.2	0.0	0.0	22.9
Mar	93.8	104.3	6.7	40.2	93.3	62.7	4.1	53.3	515.8	1.2	0.0	26.7
Apr	71.9	201.3	12.9	38.7	71.4	122.8	7.9	51.6	186.4	3.2	0.3	25.8
May	50.6	515.5	32.8	37.2	50.3	308.9	19.6	49.5	45.4	13.5	0.9	24.6
Jun	44.6	991.5	63.3	38.7	44.4	599.6	38.4	51.6	17.3	25.5	1.8	25.8
Jul	40.1	1,349.3	86.2	37.8	40.0	819.4	52.2	50.4	2.6	51.3	3.2	25.2
Aug	41.5	1,462.4	93.5	39.3	41.4	884.8	56.6	52.5	1.8	52.8	3.2	26.1
Sep	44.6	936.1	59.8	37.2	44.4	578.2	36.9	49.5	21.7	48.9	3.2	24.6
Oct	59.2	278.7	17.9	37.2	58.8	170.6	10.8	49.5	122.2	2.6	0.3	24.9
Nov	84.9	68.3	4.4	35.5	84.5	40.4	2.6	47.5	418.2	0.6	0.0	23.7
Dec	122.9	0.0	0.0	38.4	112.4	0.0	0.0	51.3	914.4	0.0	0.0	25.8
Total	837.4	5,913.6	377.8	449.6	823.0	3,591.3	229.2	599.3	3,539.1	200.2	12.9	299.5

Figure 38: Ventilation Air Conditioning Energy (MBtu) - Seattle.

The average DOAS Energy cost savings by proposed system for the Seattle location (Climate Zone 4C) are 72% over the baseline (1) and 65% over the baseline (2).

Table 29: Annual Ventilation Air Conditioning Energy Cost Comparisons - Seattle: 9.55 (Cents/kWh)[34], 9.76 ($/McF)[35].

	Baseline						Proposed				
	(1) Packaged DOAS			(2) Packaged DOAS_ERV			Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	95.01	3.5	98.5	94.53	4.61	99.1	0	83.0	83.0	16%	16%
Feb	79.99	3.9	83.9	79.52	4.81	84.3	0	47.8	47.8	43%	43%
Mar	89.59	14.8	104.3	89.06	11.73	100.8	0	53.1	53.1	49%	47%
Apr	68.65	24.7	93.3	68.18	17.79	86.0	0	21.1	21.1	77%	76%
May	48.36	57.2	105.5	48.02	36.90	84.9	0	8.2	8.2	92%	90%
Jun	42.62	106.7	149.3	42.39	67.30	109.7	0	6.9	6.9	95%	94%
Jul	38.26	143.8	182.0	38.17	89.99	128.2	0	8.0	8.0	96%	94%
Aug	39.60	155.7	195.3	39.58	97.00	136.6	0	8.2	8.2	96%	94%
Sep	42.60	100.8	143.4	42.40	64.87	107.3	0	9.6	9.6	93%	91%
Oct	56.55	32.6	89.1	56.13	22.54	78.7	0	14.6	14.6	84%	81%
Nov	81.12	10.6	91.7	80.65	8.84	89.5	0	43.2	43.2	53%	52%
Dec	117.40	3.7	121.1	107.31	5.01	112.3	0	91.8	91.8	24%	18%
Total	799.75	657.9	1,457.7	785.94	431.37	1,217.3	0	395.4	395.4	73%	68%

34 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

35 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Seattle location (Climate Zone 4C) are 32% over baseline (1) and 25% over baseline (2).

Table 30: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Seattle: 9.55 (Cents/kWh)[36], 9.76 ($/McF)[37].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	709	697	537	24%	23%
Feb	382	374	233	39%	38%
Mar	412	413	255	38%	38%
Apr	231	217	134	42%	38%
May	235	190	163	31%	14%
Jun	350	261	221	37%	16%
Jul	464	360	307	34%	15%
Aug	491	391	330	33%	15%
Sep	343	273	222	35%	19%
Oct	196	170	120	39%	29%
Nov	348	352	219	37%	38%
Dec	684	689	563	18%	18%
Total	4,846	4,387	3,305	32%	25%

36 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
37 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Chicago Results (5A)

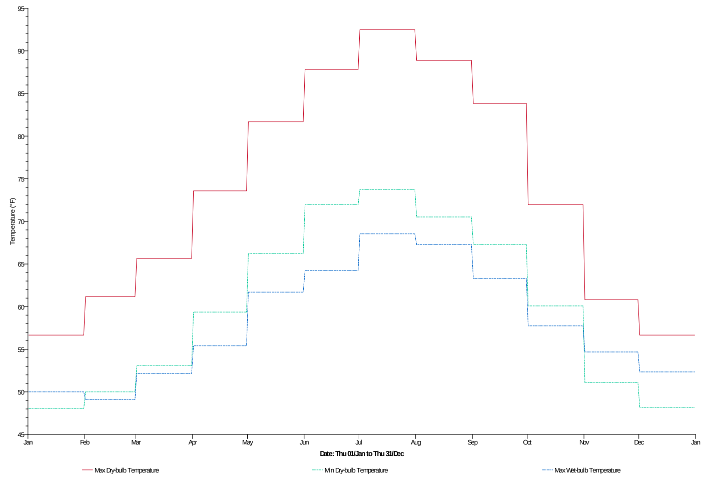


Figure 39: Design Day - Chicago.

Energy consumption by end use for the Chicago location (Climate Zone 5A) was as follows:

Table 31: Annual Ventilation Air Conditioning Energy Consumption - Chicago: 10.92 (Cents/kWh)[38], 7.84 ($/McF)[39].

	Baseline (1) Packaged DOAS				Baseline (2) Packaged DOAS_ERV				Proposed : Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	130.1	0.0	0.0	35.5	129.6	0.0	0.0	47.2	1164.1	0.0	0.0	23.7
Feb	99.8	0.0	0.0	34.0	99.3	0.0	0.0	45.4	991.5	0.0	0.0	22.6
Mar	71.7	55.1	3.5	40.2	71.2	34.6	2.3	53.3	968.9	0.3	0.0	26.7
Apr	43.1	400.3	25.5	38.7	42.7	252.0	16.1	51.6	484.4	34.0	2.1	25.8
May	4.8	1,065.9	68.0	36.9	4.6	656.2	41.9	49.2	18.8	59.5	3.8	24.6
Jun	0.4	1,633.6	104.3	38.4	0.4	1050.7	67.1	51.3	1.5	204.6	13.2	25.5
Jul	0.0	1,864.2	119.0	37.8	0.0	1288.6	82.4	50.1	0.0	397.7	25.5	25.2
Aug	0.0	1,801.2	114.9	39.3	0.0	1174.6	75.0	52.2	0.0	269.6	17.3	26.1
Sep	0.8	1,418.5	90.6	36.9	0.7	871.6	55.7	49.2	2.9	90.6	5.9	24.6
Oct	18.8	444.6	28.4	37.2	18.4	269.6	17.3	49.5	102.0	9.1	0.6	24.6
Nov	58.3	221.3	14.1	35.8	57.9	133.3	8.5	47.5	660.3	4.7	0.3	23.7
Dec	125.6	0.0	0.0	38.4	125.1	0.0	0.0	51.3	1,466.5	0.0	0.0	25.8
Total	553.3	8,905.0	568.3	448.7	549.8	5,731.6	365.8	598.2	5,860.8	1,070.0	68.3	299.2

[38] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
[39] https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Figure 40: Ventilation Air Conditioning Energy (MBtu) - Chicago.

The average DOAS Energy cost savings by proposed system for the Chicago location (Climate Zone 5A) are 59% over the baseline (1) and 49% over the baseline (2).

Table 32: Annual Ventilation Air Conditioning Energy Cost Comparisons - Chicago: 10.92 (Cents/kWh)[40], 7.84 ($/McF)[41].

	Baseline (1) Packaged DOAS			Baseline (2) Packaged DOAS_ERV			Proposed : Compact DOAS			Saving (%) by Compact DOAS over	
	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Gas ($)	Electric ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	142.0	2.8	144.8	141.48	3.70	145.2	0	93.1	93.1	36%	36%
Feb	109.0	2.7	111.6	108.46	3.56	112.0	0	79.5	79.5	29%	29%
Mar	78.3	7.7	86.1	77.72	7.08	84.8	0	78.1	78.1	9%	8%
Apr	47.1	36.4	83.5	46.65	25.07	71.7	0	42.8	42.8	49%	40%
May	5.2	91.8	97.0	5.05	58.59	63.6	0	8.4	8.4	91%	87%
Jun	0.4	139.3	139.7	0.39	91.65	92.0	0	19.2	19.2	86%	79%
Jul	0.0	158.4	158.4	0.00	111.41	111.4	0	35.2	35.2	78%	68%
Aug	0.0	153.3	153.3	0.00	102.06	102.1	0	24.5	24.5	84%	76%
Sep	0.8	121.2	122.0	0.78	76.56	77.3	0	9.7	9.7	92%	87%
Oct	20.5	40.0	60.5	20.11	26.38	46.5	0	10.7	10.7	82%	77%
Nov	63.6	21.3	84.9	63.19	14.84	78.0	0	54.0	54.0	36%	31%
Dec	137.2	3.0	140.2	136.60	4.02	140.6	0	117.0	117.0	17%	17%
Total	604.2	777.9	1,382.1	600.41	524.93	1,125.3	0	572.2	572.2	59%	49%

40 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
41 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The average HVAC energy cost savings including ventilation by the proposed system for the Chicago location (Climate Zone 5A) are 16% over baseline (1) and 12% over baseline (2).

Table 33: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons - Chicago: 10.92 (Cents/kWh)[42], 7.84 ($/McF)[43].

	Baseline (1)	Baseline (2)	Proposed	Saving (%) by Proposed over	
	Total ($)	Total ($)	Total ($)	Baseline (1)	Baseline (2)
Jan	870	873	762	12%	13%
Feb	621	635	583	6%	8%
Mar	356	358	353	1%	1%
Apr	244	225	208	14%	7%
May	259	221	168	35%	24%
Jun	493	440	369	25%	16%
Jul	642	590	516	20%	13%
Aug	566	508	433	23%	15%
Sep	378	325	259	31%	20%
Oct	167	140	112	33%	20%
Nov	325	321	303	7%	6%
Dec	810	821	763	6%	7%
Total	5,730	5,458	4,830	16%	12%

42 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
43 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Madison Results (6A)

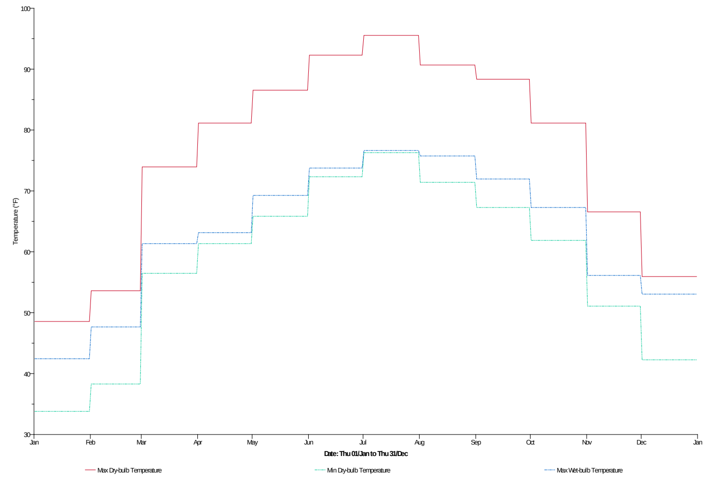


Figure 41: Design Day - Madison.

Energy consumption by end use for the Madison location (Climate Zone 6A) was as follows:

Table 34: Annual Ventilation Air Conditioning Energy Consumption - Madison: 11.45 (Cents/kWh)[44], 6.74($/McF)[45].

	Baseline								Proposed			
	(1) Packaged DOAS				(2) Packaged DOAS_ERV				Compact DOAS			
	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans	Heating	Cooling	Heat Rejection	Fans
	(Therm)	(kWh)	(kWh)	(kWh)	(Therm)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Jan	149.2	0.0	0.0	35.5	148.7	0.0	0.0	47.2	1,571.7	0.0	0.0	23.4
Feb	119.1	0.0	0.0	34.0	118.6	0.0	0.0	45.4	1,233.8	0.0	0.0	22.6
Mar	97.0	116.9	7.3	40.2	96.4	70.6	4.4	53.3	974.5	2.6	0.3	26.7
Apr	35.8	408.0	26.1	37.8	35.4	247.4	15.8	50.7	290.7	8.8	0.6	25.8
May	10.0	963.9	61.5	37.8	9.8	593.8	37.8	50.4	36.6	50.4	3.2	24.6
Jun	1.5	1,515.5	96.7	38.4	1.4	983.8	62.7	51.3	4.1	194.6	12.3	25.8
Jul	0.0	1,699.5	108.4	36.9	0.0	1,106.6	70.6	49.2	0.3	258.8	16.4	25.2
Aug	0.4	1,697.5	108.4	39.9	0.4	1,092.0	69.8	53.3	1.8	196.9	12.6	26.1
Sep	9.0	1,050.7	67.1	37.2	8.8	665.6	42.5	49.5	34.0	92.9	5.9	24.6
Oct	22.8	551.3	35.2	37.2	22.4	335.6	21.4	49.5	203.4	10.6	0.6	24.6
Nov	81.0	59.8	3.8	35.5	80.5	36.0	2.3	47.5	1,310.0	3.2	0.3	23.7
Dec	131.7	0.0	0.0	37.8	131.2	0.0	0.0	50.4	1,467.4	0.0	0.0	25.8
Total	657.3	8,062.7	514.6	448.1	653.7	5,131.4	327.7	597.6	7,128.4	818.3	52.2	299.2

44 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

45 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Figure 42: Ventilation Air Conditioning Energy (MBtu) - Madison.

The average ventilation energy cost savings by proposed system for the Madison location (Climate Zone 6A) are 59% over the baseline (1) and 52% over the baseline (2).

Table 35: Annual Ventilation Air Conditioning Energy Cost Comparisons - Madison: 11.45 (Cents/kWh)[46], 6.74($/McF)[47]

	Baseline						**Proposed**				
	(1) Packaged DOAS			**(2) Packaged DOAS_ERV**			**Compact DOAS**			**Saving (%) by Compact DOAS over**	
	Gas ($)	**Electric ($)**	**Total ($)**	**Gas ($)**	**Electric ($)**	**Total ($)**	**Gas ($)**	**Electric ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	170.8	2.4	173.2	170.23	3.18	173.4	0	107.5	107.5	38%	38%
Feb	136.3	2.3	138.6	135.77	3.06	138.8	0	84.7	84.7	39%	39%
Mar	111.0	11.1	122.1	110.42	8.65	119.1	0	67.7	67.7	45%	43%
Apr	41.0	31.8	72.8	40.53	21.16	61.7	0	22.0	22.0	70%	64%
May	11.5	71.7	83.1	11.24	45.97	57.2	0	7.7	7.7	91%	86%
Jun	1.7	111.2	112.9	1.63	73.99	75.6	0	16.0	16.0	86%	79%
Jul	0.0	124.3	124.4	0.05	82.67	82.7	0	20.3	20.3	84%	75%
Aug	0.4	124.4	124.8	0.40	81.90	82.3	0	16.0	16.0	87%	81%
Sep	10.2	77.8	88.1	10.04	51.06	61.1	0	10.6	10.6	88%	83%
Oct	26.0	42.0	68.1	25.69	27.40	53.1	0	16.1	16.1	76%	70%
Nov	92.8	6.7	99.5	92.22	5.79	98.0	0	90.1	90.1	9%	8%
Dec	150.8	2.5	153.3	150.19	3.40	153.6	0	100.6	100.6	34%	34%
Total	752.7	608.3	1361.0	748.45	408.22	1156.7	0	559.3	559.3	59%	52%

46 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.
47 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

The whole building HVAC energy cost savings including ventilation by the proposed system for the Madison location (climate zone 6A) are 13% over baseline (1) and 11% over baseline (2).

Table 36: Annual HVAC Energy Cost Total (Ventilation + Indoor Air Conditioning) Comparisons – Madison: 11.45(Cents/kWh)[48], 6.74($/McF)[49].

	Baseline (1)	**Baseline (2)**	**Proposed**	**Saving (%) by Proposed over**	
	Total ($)	**Total ($)**	**Total ($)**	**Baseline (1)**	**Baseline (2)**
Jan	1,123	1,123	1,019	9%	9%
Feb	848	848	797	6%	6%
Mar	606	603	562	7%	7%
Apr	196	185	150	24%	19%
May	255	230	182	29%	21%
Jun	440	403	342	22%	15%
Jul	535	494	436	19%	12%
Aug	486	443	373	23%	16%
Sep	298	271	224	25%	17%
Oct	170	155	131	23%	16%
Nov	670	668	558	17%	16%
Dec	871	871	850	2%	2%
Total	6,498	6,294	5,624	13%	11%

48 https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

49 https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

Conclusion: LG DOAS Design Guide

1. The results in this study suggest that simulated DOAS configurations have system energy cost saving potentials ranging from 72% to 87% and 52% to 84% when compared to the simulated baseline system (1) and baseline system (2) in all climates.
2. Instead of a large package-type DOAS that can supply air to the entire building, the LG VRF system with a high-efficiency split condensing unit connected can supply fresh air to the area using several compact DOAS units. A correctly sized DOAS can be enough to support only the building's ventilation and ventilation loads, reducing installation space and energy use.
3. Building design professionals implementing ASHRAE Standard 62 Ventilation requirements are most concerned with occupant comfort and moisture control. Removing moisture from the outdoor air provides a cost-effective way to prevent moisture-related indoor air quality problems. By applying appropriate temperature control strategies, a DOAS can be more efficient by precisely controlling the temperature of the air delivered to the space. To choose the most economical temperature control system, the design engineer must consider the DOAS energy efficiencies, size, layout, and fresh air requirements of each application.
4. Integrating higher efficiency into the DOAS with neutral air can be a good way to conserve energy throughout the building, and to keep the occupants' comfort levels optimum. Cold-temperature air from a DOAS can supply air to dehumidify the building space. With the help of the cold air, the primary HVAC system equipment can be downsized to conserve energy; however, the engineer should be aware that cold air drafts can cause thermal discomfort.
5. Heat pump technology can enable the electrification of building ventilation system. Unlike gas furnaces that burn fuel to produce heat, heat pumps use electricity to send heat where it's needed or remove it where it's not needed. Most net-zero future scenarios include electrification of heating to some extent in most buildings, from all-electric heating infrastructure with heat pumps.

References

ANSI/AHRI Standard 920- 2012

- Standard for Performance Rating of DX-Dedicated Outdoor Air System Units.

ANSI/ASHRAE/IESNA Standard 90.1-2013

- Table 5.5-1: Building Envelope Requirements for Climate Zone 1-6.
- Table 6.8.1A: Electronically Operated Unitary Air Conditioners and Condensing Units—Minimum Efficiency Requirements.
- Table 6.8.1B: Electrically Operated Unitary and Applied Heat Pumps—Minimum Efficiency Requirements.
- Table 6.8.1E: Warm Air Furnaces and Combination Warm Air Furnaces/Air-Conditioning Units, Warm Air Duct Furnaces and Unit Heaters.
- Table 7.8: Performance Requirements for Water Heating Equipment.
- Table 9.5.1: Lighting Power Densities Using the Building Area Method.

Electricity Rates

- https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.

Natural Gas Rates

- https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

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