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A desktop study into the energy efficiency and environmental benefits of CO_2 refrigeration in USA supermarkets

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Profile of an Average U.S. Supermarket's Greenhouse Gas Impacts from Refrigeration Leaks Compared to Electricity Consumption

U.S. ENVIRONMENTAL PROTECTION AGENCY GREENCHILL ADVANCED REFRIGERATION PARTNERSHIP

U.S. Supermarket Store Size	46,000 ft^2
Annual Electricity Consumption Intensity for U.S. Supermarkets	51 kWh/ft^2
Annual Electricity Consumed (Annual Consumption Intensity x Store Size)	2,346,000 kWh/year
Electricity Use Emission Factor (U.S. Average)	1.30 lbs of CO_2 per kWh
Annual CO_2 Emissions from Electricity Consumption	3,049,800 lbs of CO_2 per year
Typical Commercial Refrigerant Used	R404A
Global Warming Potential (AR4 standard)	3,921.6
Commercial Refrigeration Charge Size	3,500 lbs
Annual Commercial Refrigeration Leak Rate	25% per year
Annual Volume of Commercial Refrigerant Leaked	875 lbs per year
Annual CO_2 eq of R404A Leaked	3,431,400 lbs CO_2 eq per year

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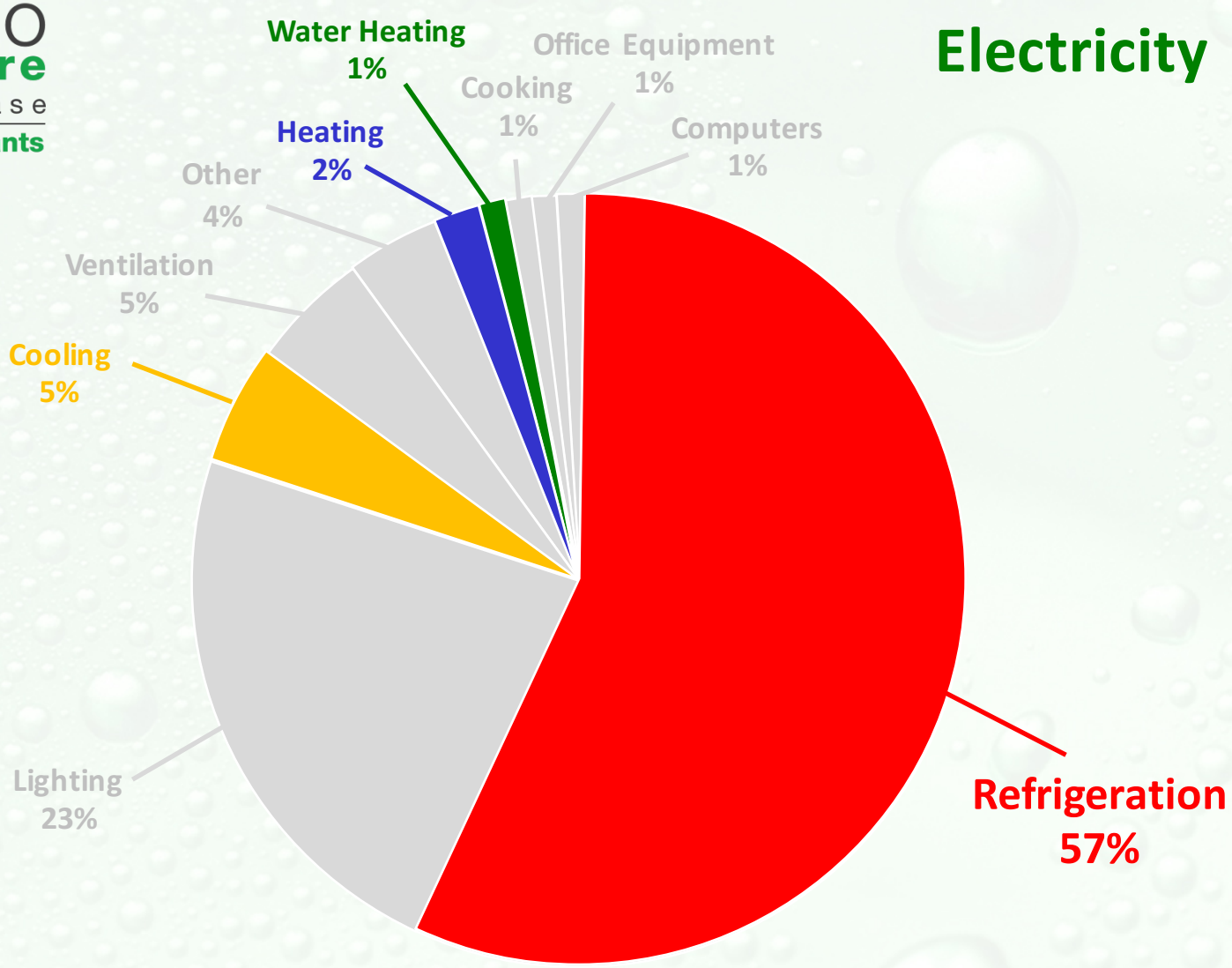
Electricity



Annual Electrical Energy Consumption = 51 kWh/ft²

Annual Cost = $5.31/ft² ≡ $0.1041/kWh

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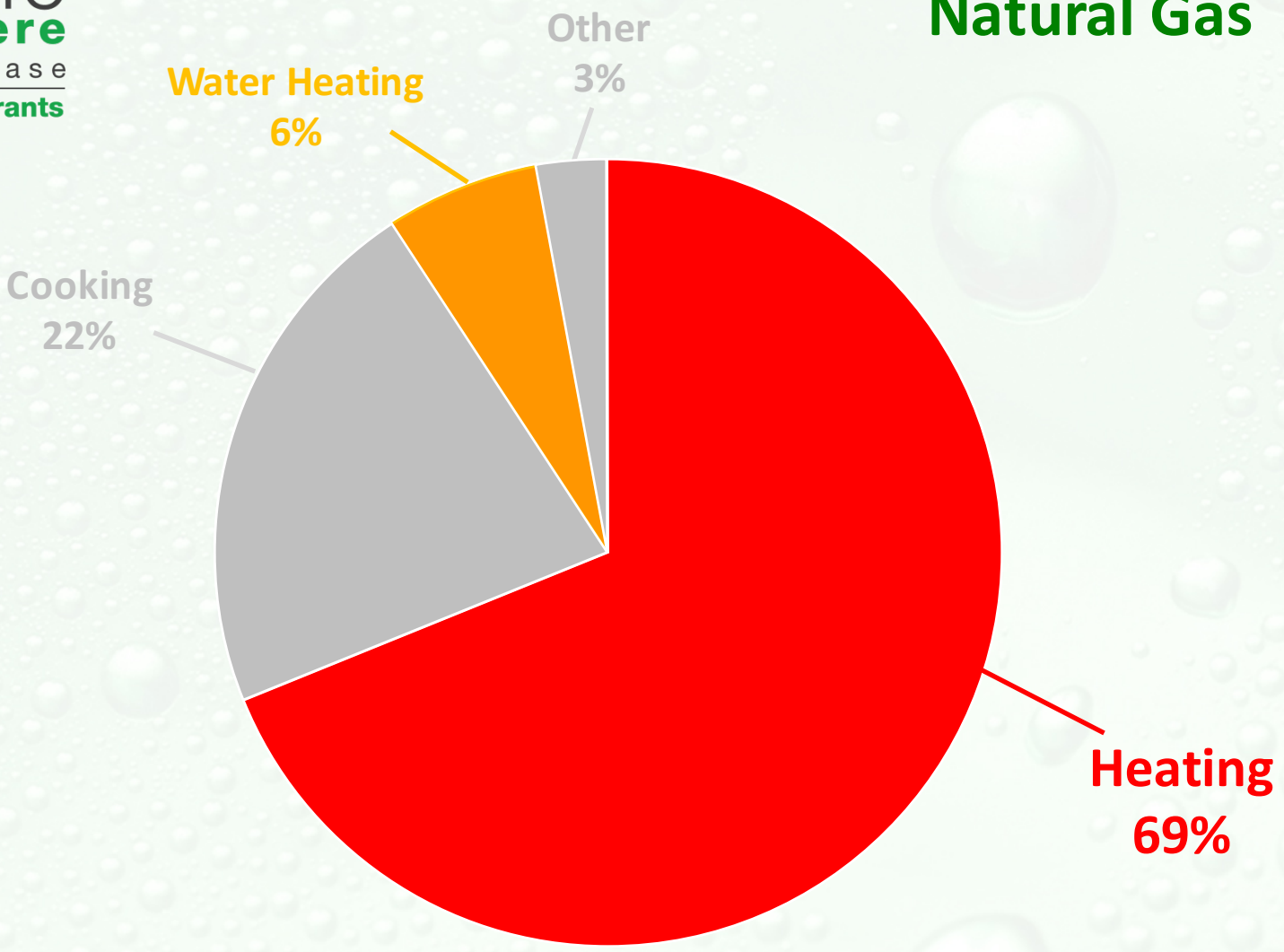
Natural Gas



Annual Natural Gas Consumption = 41,000 BTUs/ft^2

Annual Natural Gas Cost = \$0.38/ft^2 ≡ \$0.93/therm

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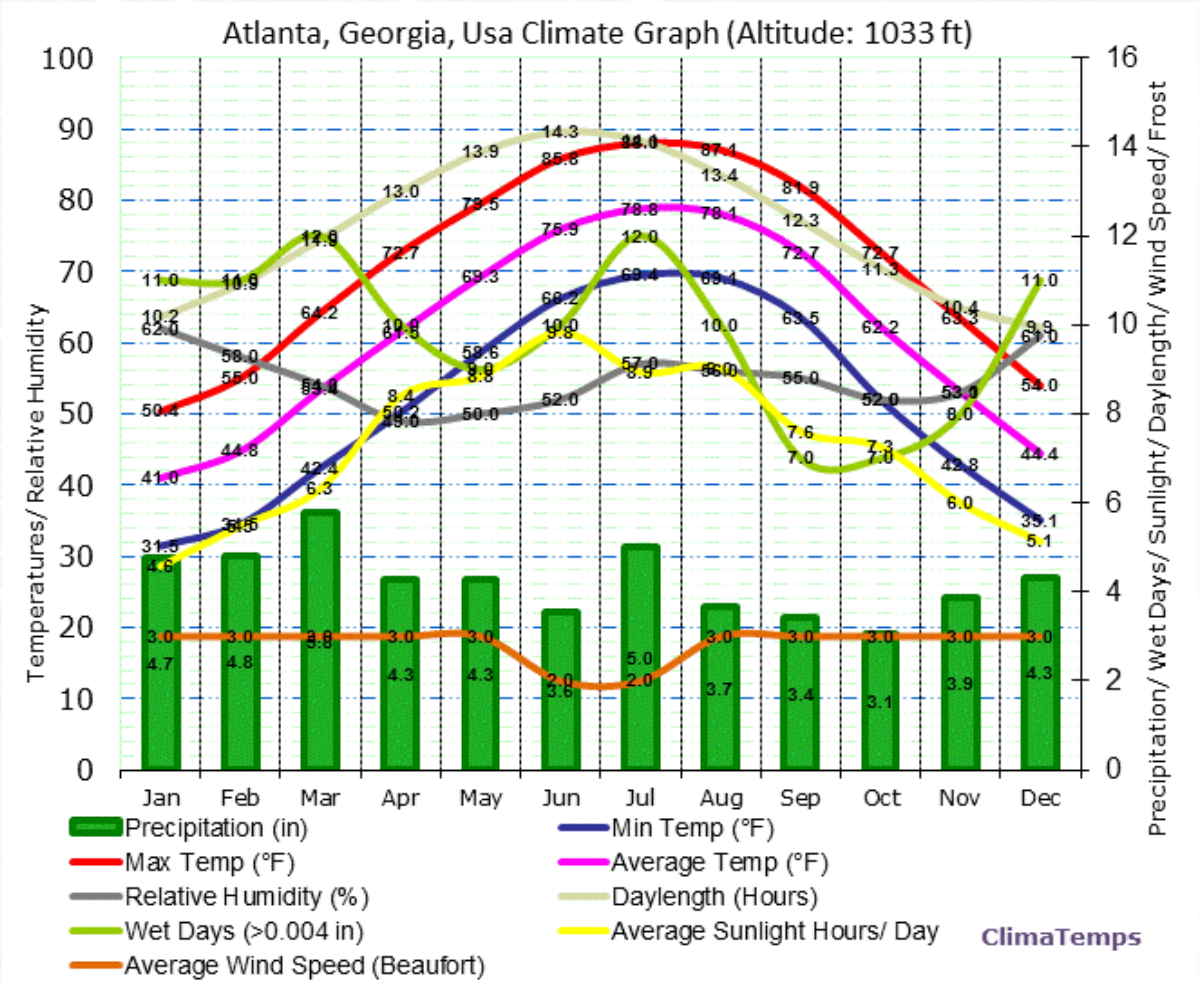

Climate Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Temperature °C (°F)	10 (50)	13 (55)	18 (64)	23 (73)	26 (80)	30 (86)	31 (88)	31 (87)	28 (82)	23 (73)	17 (63)	12 (54)	22 (71)
Average Temperature °C (°F)	5 (41)	7 (45)	12 (53)	16 (62)	21 (69)	24 (76)	26 (79)	26 (78)	23 (73)	17 (62)	12 (53)	7 (44)	16 (61)
Average Min Temperature °C (°F)	0 (31)	1 (35)	6 (42)	10 (50)	15 (59)	19 (66)	21 (69)	21 (69)	18 (64)	11 (52)	6 (43)	2 (35)	11 (51)

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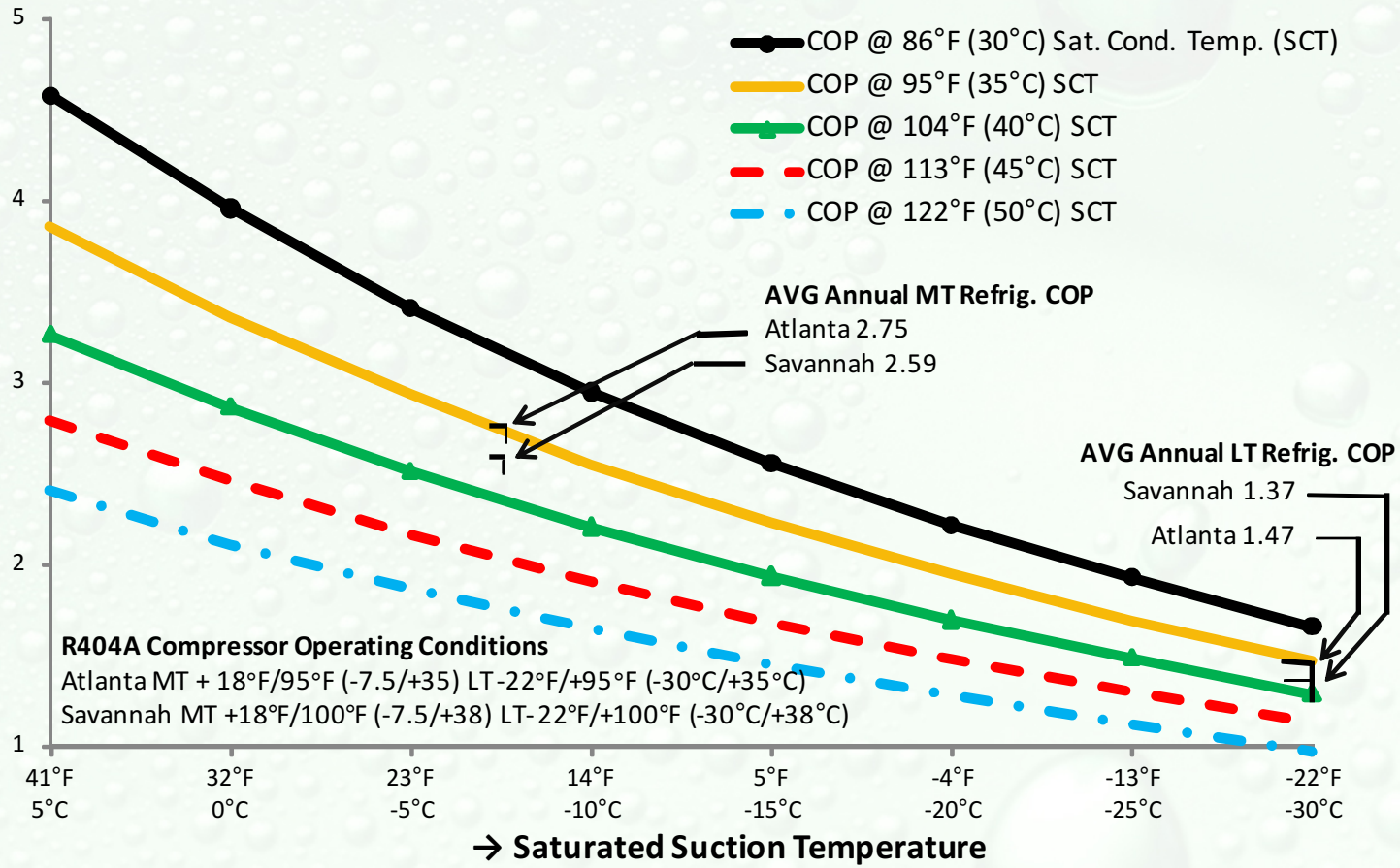
Variation of COP with saturated suction temperature (SST) of various saturated condensing temperatures (SCTs) with air cooled condensing for a commercially available R404A compressor – 95cfm @ 50Hz.



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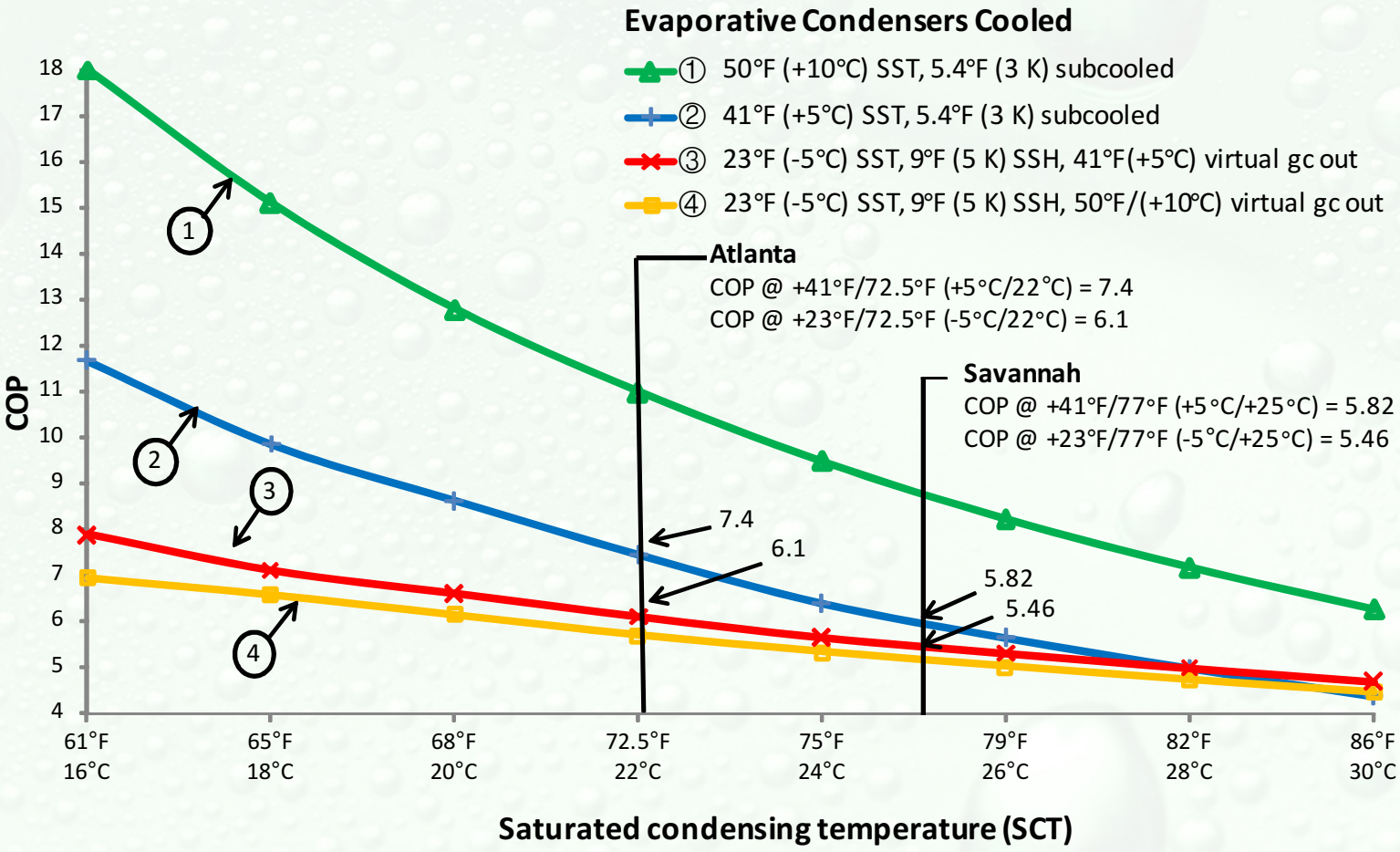
Variation of COP with saturated condensing temperature (SCT) of various saturated suction temperatures (SSTs) for a commercially available CO_2 compressor – 40HP and 16 cfm @ 50Hz.



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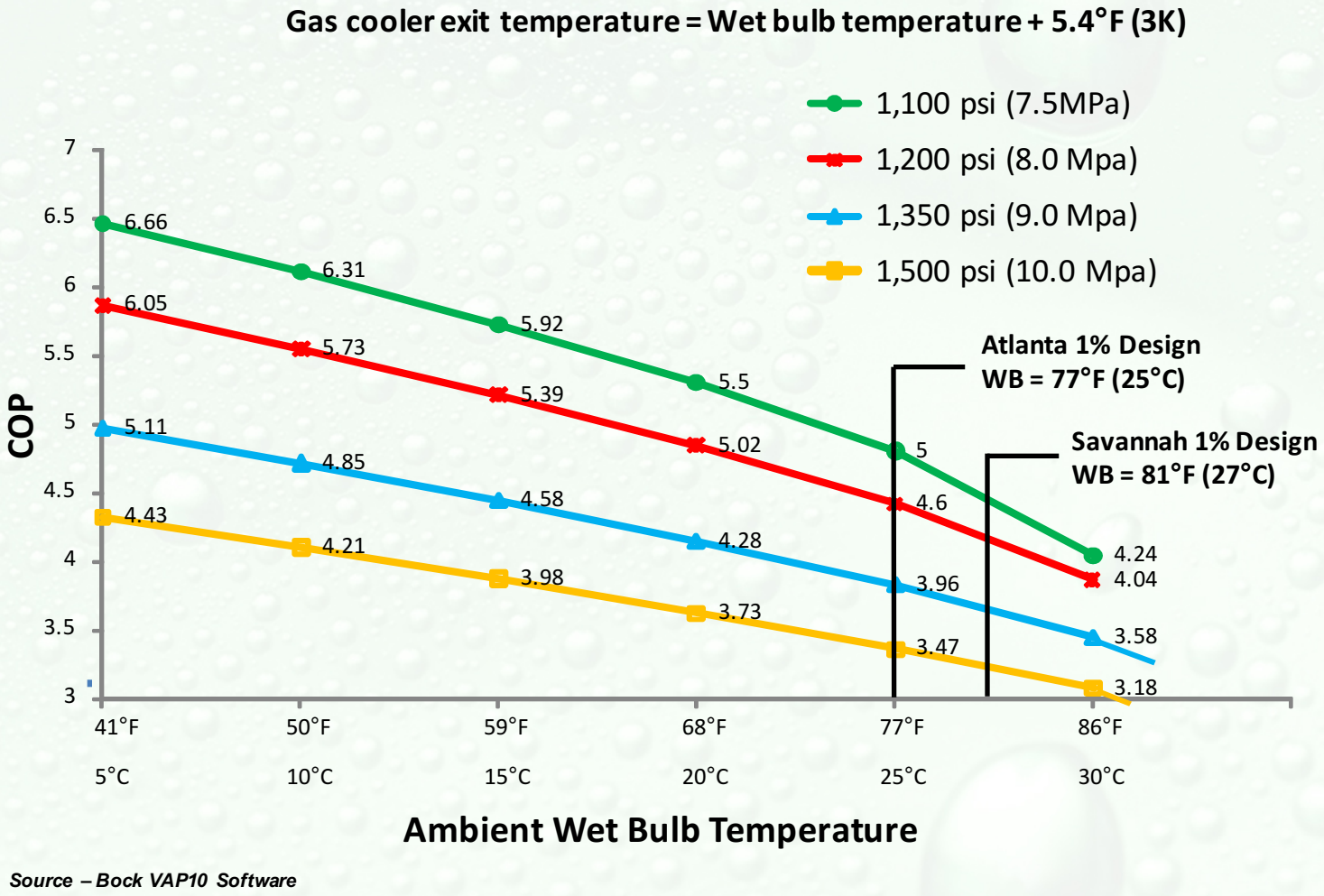
COP vs ambient & wet bulb for varying transcritical discharge pressures +5°C SST, 5 K SSH for chilled water AC and parallel compression.



Source – Bock VAP10 Software

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Summary of electrical energy consumed (EEC) by consumer and allocation to refrigeration, AC and heating plus evaluation of total emissions due to EE consumption and refrigerant (R404A) losses and annual EE cost

EE Consumer		EEC		
No	DESCRIPTION	% (1)	Unit	Qty
1	Refrigeration	57	kWh/ft²annum	29.1
2	Cooling (AC)	5		2.55
3	Space Heating	2		1.02
4	Water Heating	1		0.51
5	Total cooling & heating	65		33.2
6	Other	35		17.8
7	Total	100		51 (1)

	Total Annual EEC & Emissions		
No	Parameter		Value (2)
8	Store size, ft²	=	46,000
9	Total annual EEC, kWh	=	2,346,000
10	Total annual EE emissions, lbs	=	3,049,800
11	Total annual R404A emissions, lbs	=	3,431,400
12	Total annual EE + R404A emissions, lbs	=	6,481,200
13	Total annual EE cost @ $5.31/ft² (2)	=	244,260

(1) From Slide 3
(2) From Slide 2

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Analysis of electrical energy consumption (EEC) by consumer for refrigeration, AC, heating and cooling (RACHC) and evaluation of annual reduction in EEC in quantity and percentage in Atlanta

Parameter			EEC by Consumers and COP					
			Refrigeration					
No	Description	Unit	Total	MT	LT	AC	Heat	Total
1	Total energy consumption	kWh/ft²/a	29.1	-	-	2.55	1.53	33.18
2	Estimated cond. and evap. EEC - fans, 10%	kWh/ft²/a	2.91	-	-	0.26	-	3.17
3	Compressor EEC & Heating	kWh/ft²/a	26.19	19.64(1)	6.55(2)	2.29	1.53	30.01
4	COP existing systems. From Slide 6	-	-	2.75	1.47	3.84	1.0	-
5	Capacity = COP x EEC	kWR/ft²/a	-	54.0	9.62	8.8	1.53	-
6	CO_2 System COPs. From Slide 7	-		5.5(3)	2.44	7.4	0	-
7	CO_2 energy = Cap. ÷ COP	kWh/ft²/a		9.82	3.94	1.19	0	14.95
8	EEC reduction (3 – 7)	kWh/ft²/a		9.82	2.61	1.10	1.53	15.06
9	Total annual EEC reduction in 46,000 ft² store, 46,000 x 15.0 kWh with CO_2 system							690,000
10	EEC with R404A / CO_2 system for RACH in 46,000 ft² store, kWh							1,527,200 / 837,200
11	EEC with R404A / CO_2 system all consumers in 46,000 ft² store @ 51kWh/ft², kWh (4)							2,346,000 / 1,656,000
12	Reduction in RACHC EEC, %							45.2%
13	Reduction in store EEC over all consumers, %							29.4%

Notes:
(1) 75% of refrigeration EEC by MT refrigeration
(2) 25% of refrigeration EEC by LT refrigeration
(3) Actual COP of 6.1 reduced by 10% to 5.5 to cover parallel compression during hot weather and heat pumping in cold weather
(4) From Slide 2

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Summary of natural gas consumed by consumer, allocation of heat to space and water heating and annual cost

Natural Gas Consumed						
Parameter					Derived Value	
No	NG Consumer	%	BTUs/ft²/ annum	No	Parameter	Qty & Unit
1	Space heating	69	28,290	11	41,000 BTUs/ft²/year (2)	12 kWh
2	Water heating	6	2,460	12	To Heating	75%
3	Total heating	75	30,750	13	Then heat used/ft²/year	9 kWh
4	Other – 88% cooking	25	10,250	14	Total gas heat/year	414,000 kWh
5	Total	100	41,000	15	Boiler efficiency 75%	75%
6	Store floor area, ft² (1)		46,000	16	Gas heat used/ft²/year	6.75 kWh
7	Total NG consumed, therms		18,860	17	Electric heat used/ft²/year	1.53 kWh
8	Annual emissions, lbs		254,219	18	Total heat used/ft²/year	8.28 kWh
9	Annual NG cost @ $0.38/ft²		$17,480	19	Reduced annual NG cost	$4,370.00
10	One (1) kWh		3,412 BTUs	20	Reduction in annual NG cost	$13,110.00

Notes: (1) From Slide 2
(2) From Slide 4

Estimated Reduction in Annual CO_2 eq Emissions

No	Emission Source	Current CO_2 emissions		CO_2 Refrigeration and Heat Recovery		
		Unit	Quantity	Reduction in CO_2 emissions		Estimated total CO_2 emissions – lbs From all sources
				lbs	%	
1	EEC	lbs	3,049,800 (1)	897,000	29.4	2,152,800
2	NGC	lbs	254,219 (2)	190,664	75	63,555
3	Refrigerant leaks (RL)	lbs	3,431,400 (1)	3,430,525	99.975	875
4	Total		6,735,419	4,518,189	67.1	2,217,230

Notes: (1) From Slide 3
(2) Calculated @ 13.48 lbs / therm

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Estimated Reduction in Annual Utility & Refrigerant Costs

Cost Centre		Unit Name & Cost		Reduction in consumption		Present Annual Cost	Reduction in annual cost	
No	Description	Unit	$	Unit	Quantity	$	$	%
1	Electrical energy	kWh $/ft^2	0.1041 5.31 (1)	kWh	690,000	244,260	71,829	29.4
2	Natural gas	therm $/ft^2	0.927 0.38 (1)	therms	14,145	17,480	13,110	75
3	Refrigerant (2)	Δ $/lb	6-5=1	875 lbs	0	5,250	4,375	75
4	Totals					266,990	89,314	33.5
5	Totals per square foot floor area					$5.80	$1.94	33.5
6	Say 90% realization then annual cost reduction						80,383	30.1

Notes: (1) From Slide 3
(2) 875 lb of refrigerant loss in both cases but CO_2 costs $5 / lb less than R404A. Technicians' time charges are assumed to be the same for each refrigerant. From Slide 2

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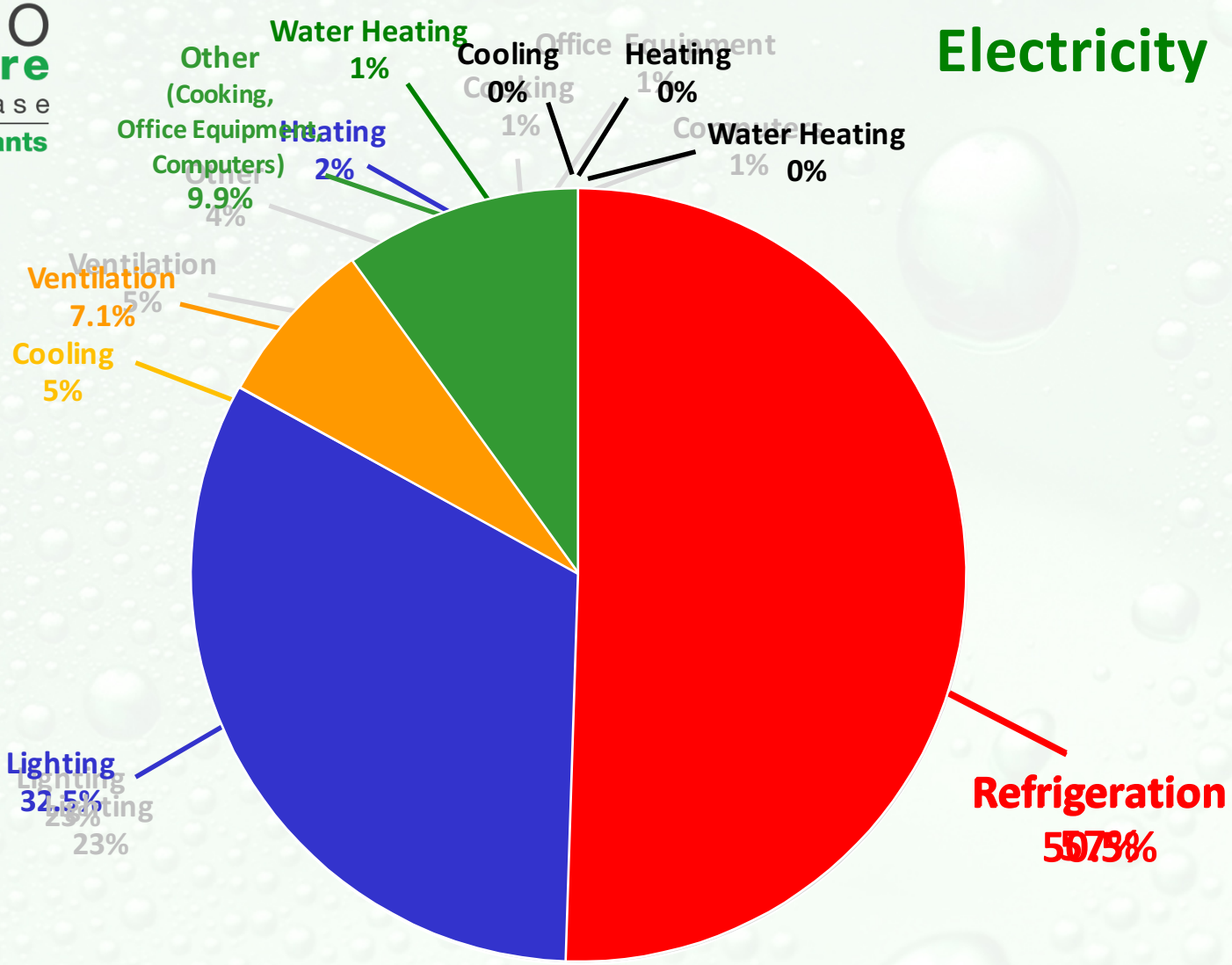

Annual Electrical Energy Consumption = 51 kWh/ft² - 36 kWh/ft² = 15kWh/ft² Saved

Annual Cost = $5.31/ft² ≡ $0.1041/kWh CO_2 System $3.75/ft² = $1.56/ft² Saved

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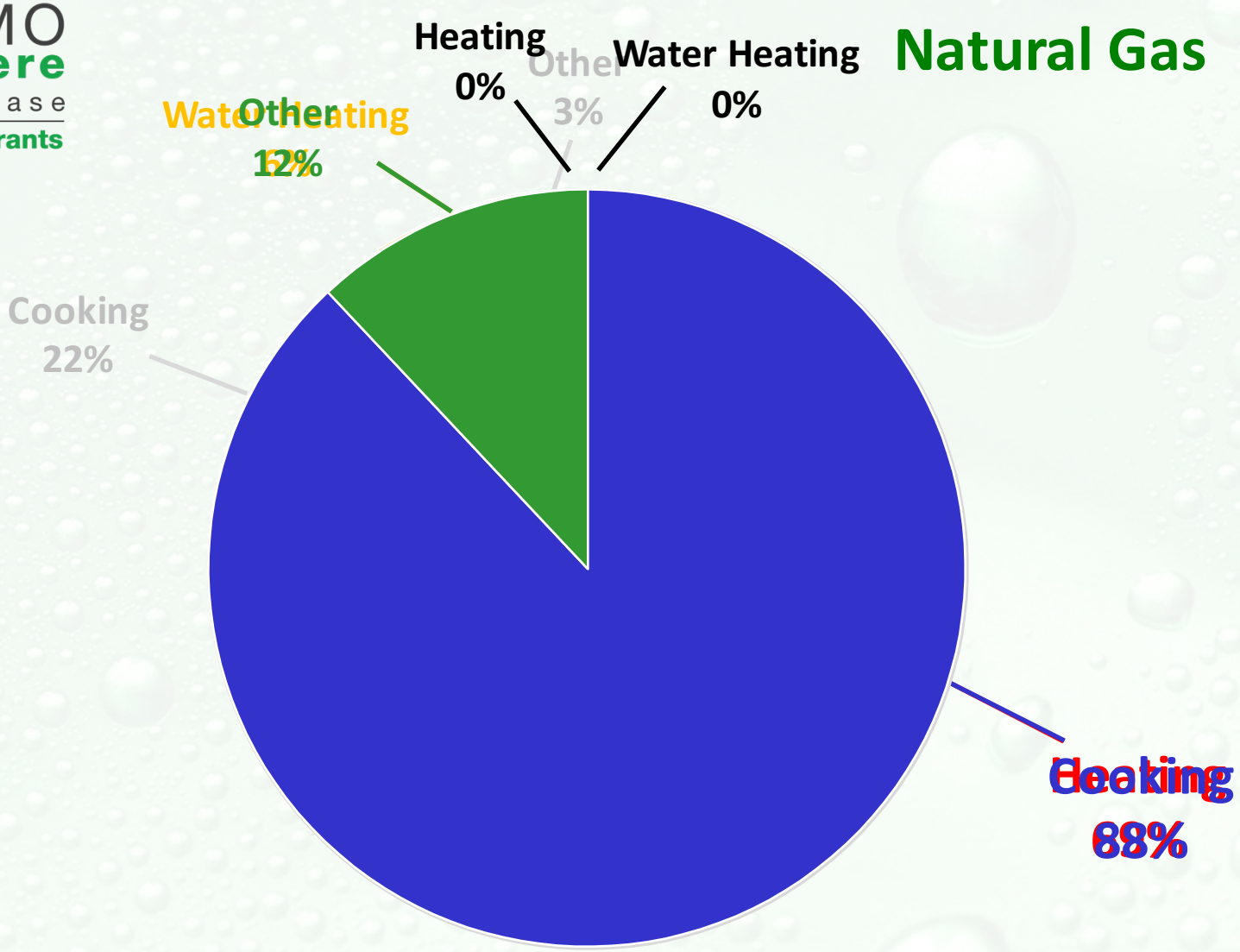
Natural Gas



Annual Natural Gas Consumption = 41,000 BTUs/ft² - 10,250 BTUs/ft² = 30,750 BTUs/ft² Saved

Annual Natural Gas Cost = $0.38/ft² ≡ $0.93/therm CO_2 System $0.095/ft² = $0.285/ft² Saved

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Refrigerant Heat Recovery

At one time, recovery and use of heat from refrigeration systems to provide space heating in grocery stores was used extensively and provided all or most of the heat in most stores across the US. However, refrigerant heat recovery has become less common in recent decades, largely to reduce refrigerant change and leakage. To reduce energy usage and operating costs and to meet sustainability objectives, many grocery chains are again considering refrigerant heat recovery.

California Title 24 Heat Recovery Requirements

California's 2013 Building Energy Efficiency Standards for Residential and Non-residential Buildings (Title 24) include mandatory requirements for commercial refrigeration and refrigeration heat recovery. Section 120.6(b) 4 requires that grocery stores use at least 25% of the heat from refrigeration for space heating in new stores (CEC 2013).

Source: ASHRAE et al. Advanced Energy Design Guide for Grocery Stores. Page 62. 3/18/2015