Importance of Energy Efficiency in Transition to HCFC-22 Alternatives

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Total Equivalent Warming Impact - TEWI

- TEWI is a tool used by DOE (and others) to estimate the global warming impact of various technologies that use green house gases including R-22 and its alternatives

Total Equivalent Warming Impact - TEWI

- TEWI is an estimate of total emissions of CO_2 to the atmosphere due to the operation of a given system over its lifetime and is the sum of the following two components:
  - **Direct:** equivalent CO_2 emissions caused by direct leakage or loss of refrigerant fluid
  - **Indirect:** CO_2 emissions due to energy consumption by the system – ***inversely proportional to energy efficiency***

R-22 Applications Covered

- Unitary packaged equipment
  - Residential heat pumps & central ACs
  - Rooftop ACs
- Supermarket refrigeration

Energy Consumption for These Applications is Significant

- Electric cooling for homes used nearly 2 quads of primary energy in 2001
  - Unitary systems responsible for bulk
- 2001 supermarket refrigeration energy total about 0.35 quads
- Total US 2001 energy use nearly 100 quads
  - R-22-based systems used about 2-3% of this total

Unitary – Split System Residential HP

- Principal alternative refrigerant to R-22 for these systems is R410A
  - 410A showed potetial for about 5% efficiency improvement in optimized system designs
    - Alternative Refrigerants evaluation Program coordinated by ARTI during the 90's
  - Many mfrs now offer both R22 and R410A systems with essentially equal SEER and HSPF

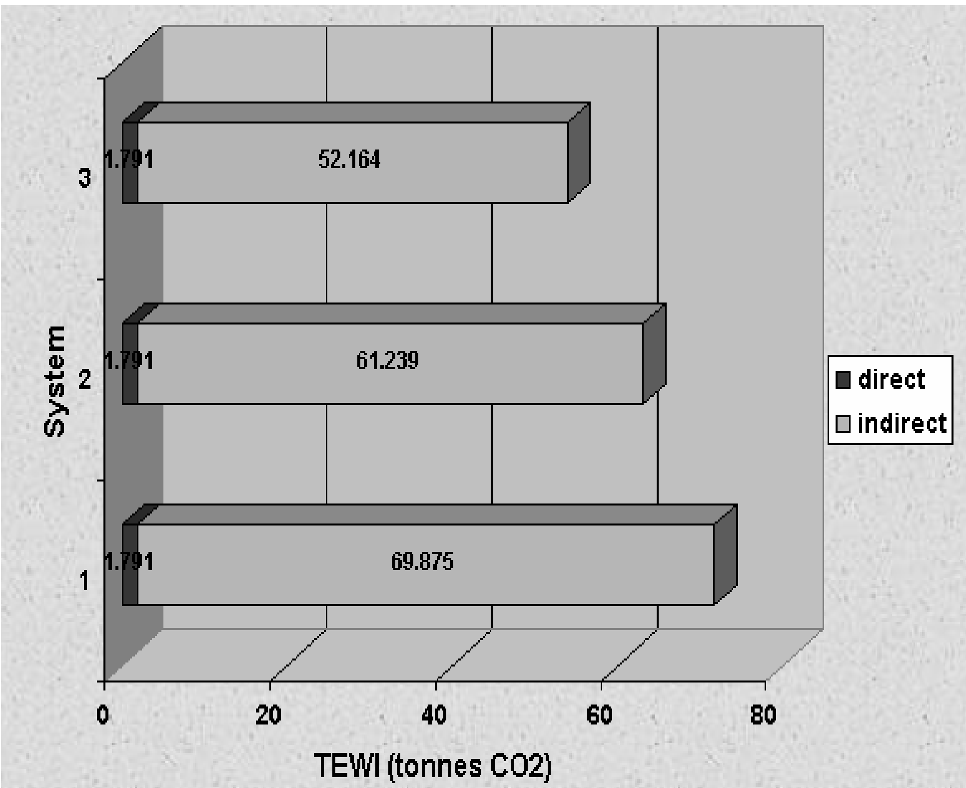
Unitary – Split System Residential HP

- Analysis assumptions
  - 3-ton unit in 1800 ft^2 house in Atlanta, GA
  - 15-year life
  - 0.65 kg CO_2/kWh electricity consumed
  - R-410A; GWP=1730 kg CO_2/kg refrigerant
    - 2% annual loss & 15% loss at end of life
  - SEERs: 12, 14, 18.6 (appx. market best)
  - Heat pump capacity: 3-ton

TEWI Comparison – Heat Pumps

System	R410A Charge (kg)	Annual Energy (kWh)	TEWI (tonnes of CO_2)		
			Direct	Indirect	Total
1 - Heat Pump (SEER=12.0; HSPF=8.0)	**2.34**	**7,170**	**1.8**	**69.9**	**71.7**
2 - Heat Pump (SEER=14.0; HSPF=9.0)	**2.34**	**6,280**	**1.8**	**61.2**	**63.0**
3 – "Market Best" Heat Pump (SEER=18.6; HSPF=9.85)	**2.34**	**5,350**	**1.8**	**52.2**	**54.0**
Results for site in Atlanta, GA – 15 year service life Annual refrigerant loss – 2% of charge End of life refrigerant loss – 15% of charge					

TEWI Comparison – Heat Pumps

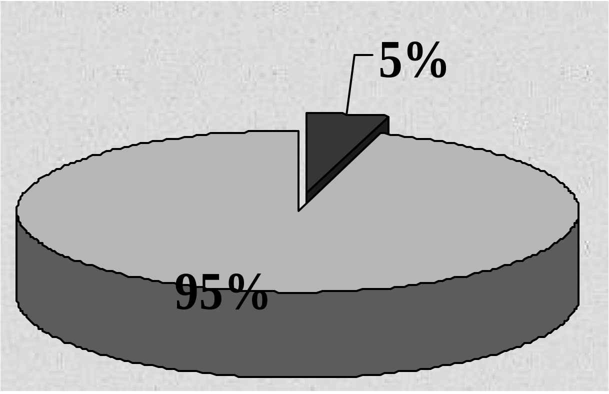


- Increased efficiency yields significant TEWI reduction
  - 2 vs 1: 12% drop
  - 3 vs 2: 14% drop
- Going from SEER 12 (system 1) to 14 (system 2) means about 8.5 tonnes reduction in lifetime CO_2 emissions
  - about 3x total direct effect

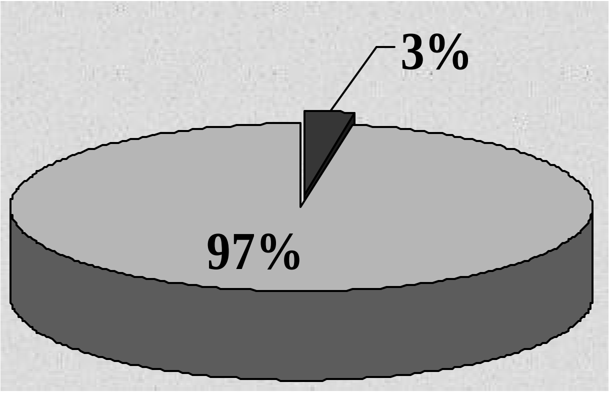
TEWI Comparison – Heat Pumps

- TEWI is relatively insensitive to doubling of annual refrigerant loss rate
  - – typical of factory-assembled sealed systems

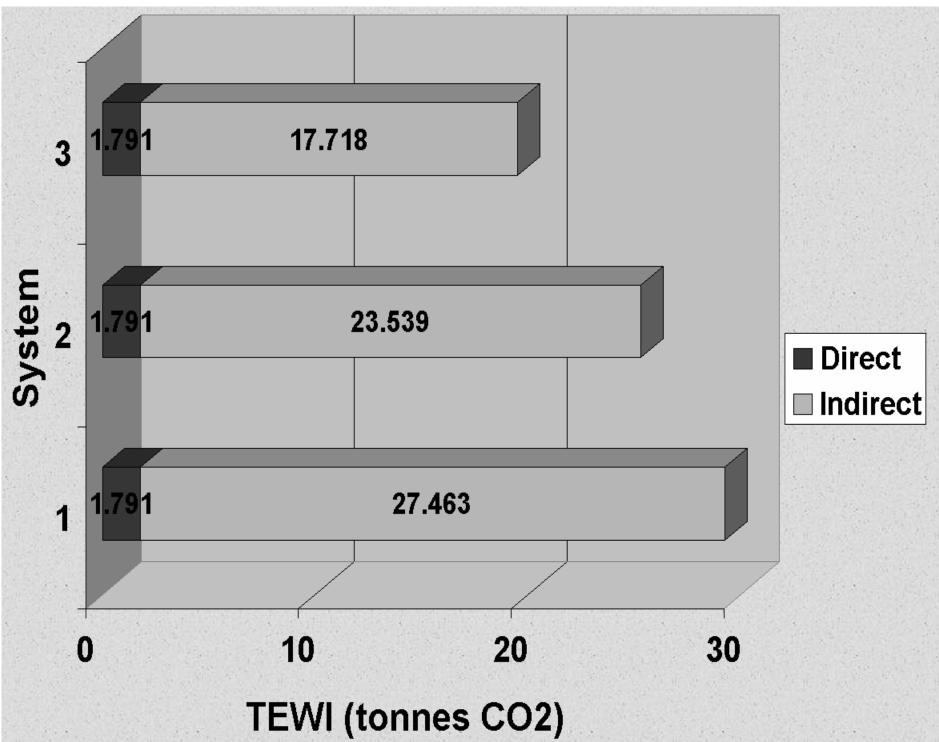
4% annual loss rate



2% annual loss rate



TEWI Comparison – Central AC



- Smaller TEWI for cooling-only units vs heat pumps
  - indirect part still predominant (>90%)
- 92% AFUE gas furnace would add ~ 31.7 tonnes indirect CO_2 emission from gas usage to total system (H&C) TEWI
  - indirect > 95% of total

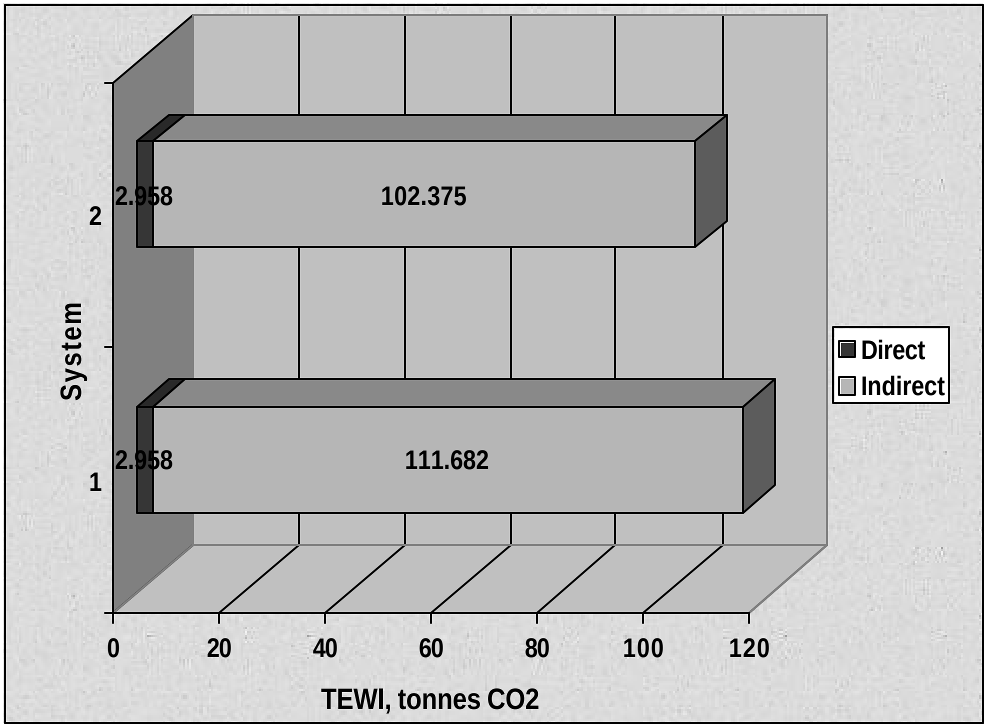
Unitary – Single Package Rooftop AC

- Principal alternative – R410A
- Analysis assumptions
  - 15-year life
  - 7-½ ton unit in Atlanta, GA
  - 1400 equivalent full load hours
  - 0.65 kg CO_2/kWh electricity consumed
  - 5.7 kg R-410A; 1% annual loss & 15% EOL loss
  - EERs: 11 (system 1), 12 (system 2)

TEWI Comparison – Rooftop AC

System	R410A Charge (kg)	Annual Energy (kWh)	TEWI (tonnes of CO_2)		
			Direct	Indirect	Total
1 – Rooftop AC, EER=11.0	**5.70**	**11,450**	**3.0**	**111.7**	**114.7**
2 – Rooftop AC, EER=12.0	**5.70**	**10,500**	**3.0**	**102.4**	**105.4**
Results for site in Atlanta, GA – 15 year service life Annual refrigerant loss – 1% of charge End of life refrigerant loss – 15% of charge					

TEWI Comparison – Rooftop AC

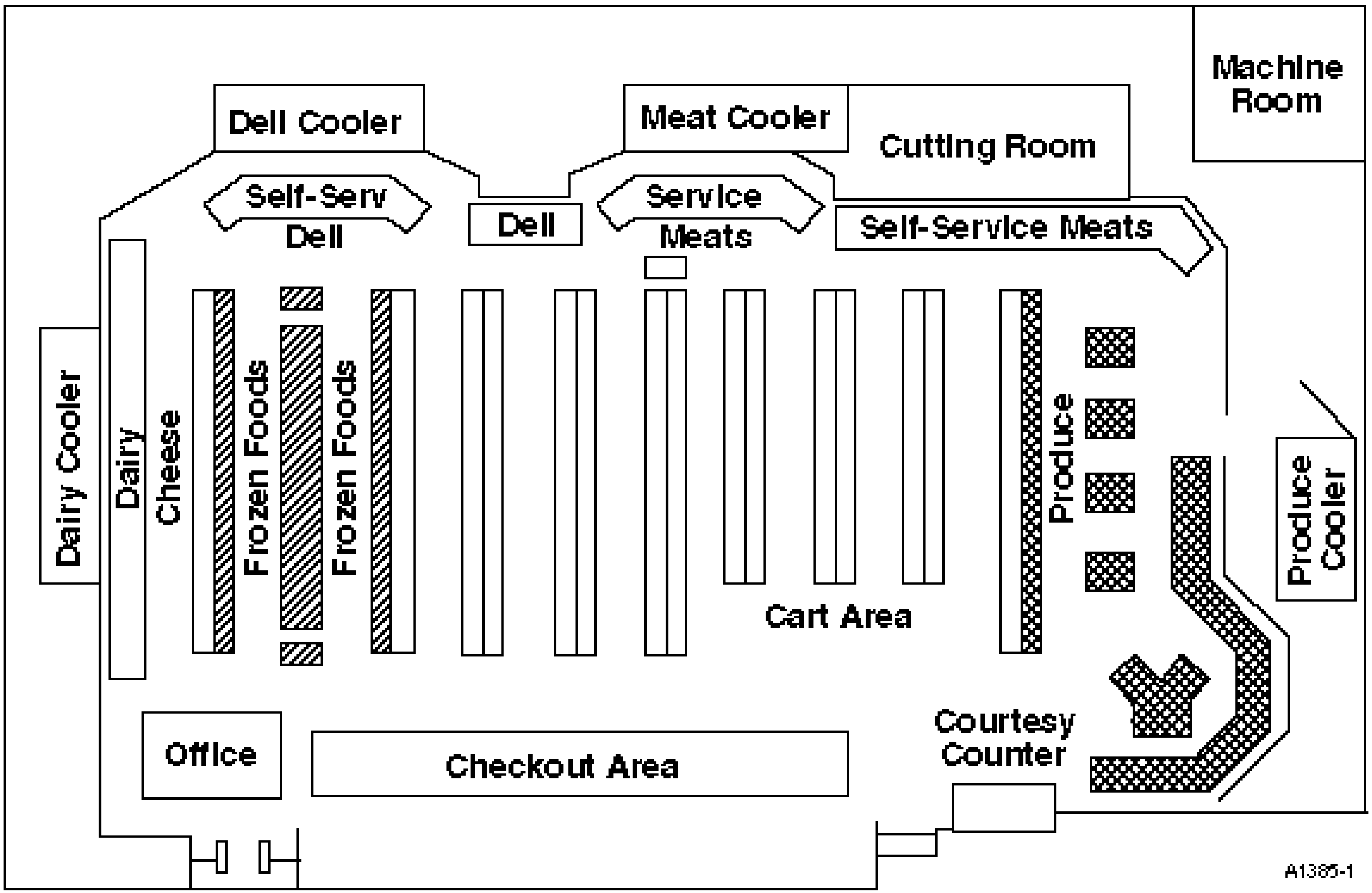


- Improved EER yields drop of about 9 tonnes in CO_2 emissions
  - compares with total direct effect of about 3 tonnes for assumed leak rate

Supermarket Refrigeration

- Many new supermarket systems today use R22 for "medium temperature or MT" loads (diary, deli, fresh meat, etc.) and R404A or R507A for "low temp or LT" loads (frozen foods)
- Conventional systems have high charge (1000-2000 kg), about ? for the MT systems
  - central compressor location & long refrigerant lines
- Historically high refrigerant loss rates
  - many field connected joints

Representative Supermarket Layout



Supermarket Refrigeration – Future Alternatives

- Refrigerant alternatives to R22
  - HFC refrigerants R404A or R507A
    - higher GWPs exacerbate direct effects
  - Ammonia or hydrocarbons
    - lower GWP but only feasible where isolation from public can be assured; additional safety and control features would increase system cost
- Alternate system designs which require less refrigerant

Supermarket Refrigeration TEWI Analysis Assumptions

- 40,000 ft^2 supermarket in Washington, DC
  - 280 kBtu/h LT load; 840 kBtu/h MT load
  - 15-year life
- Baseline system: multiplex direct expansion (DX)
  - Multiple parallel compressors in central machine room
  - DX evaporators in each display case or storage room
  - 1,360 kg of refrigerant; 33% R404A (frozen foods) and 67% R22 (fresh foods, dairy, deli, etc.)
  - Air-cooled condensers or evaporative condensers

Alternate System Designs

- Low-Charge Multiplex DX assumptions
  - Multiplex with reduced refrigerant charge
    - refrigerant charge is 906 kg (all R404A)
  - System controls limit charge on condensing side of system and enable lower minimum condensing pressures than baseline
    - lower condensing pressures mean some efficiency increase potential vs baseline system

Alternate System Designs, contd.

- Distributed compressor system assumptions
  - Compressor cabinets located near display cases
    - multiple parallel compressors in each cabinet
    - direct expansion (DX) evaporators in display cases
    - shorter suction lines ?   better compressor efficiency
  - Central fluid loop to reject heat from all cabinets
    - evaporative cooling tower
    - system charge is 405 kg, R404A

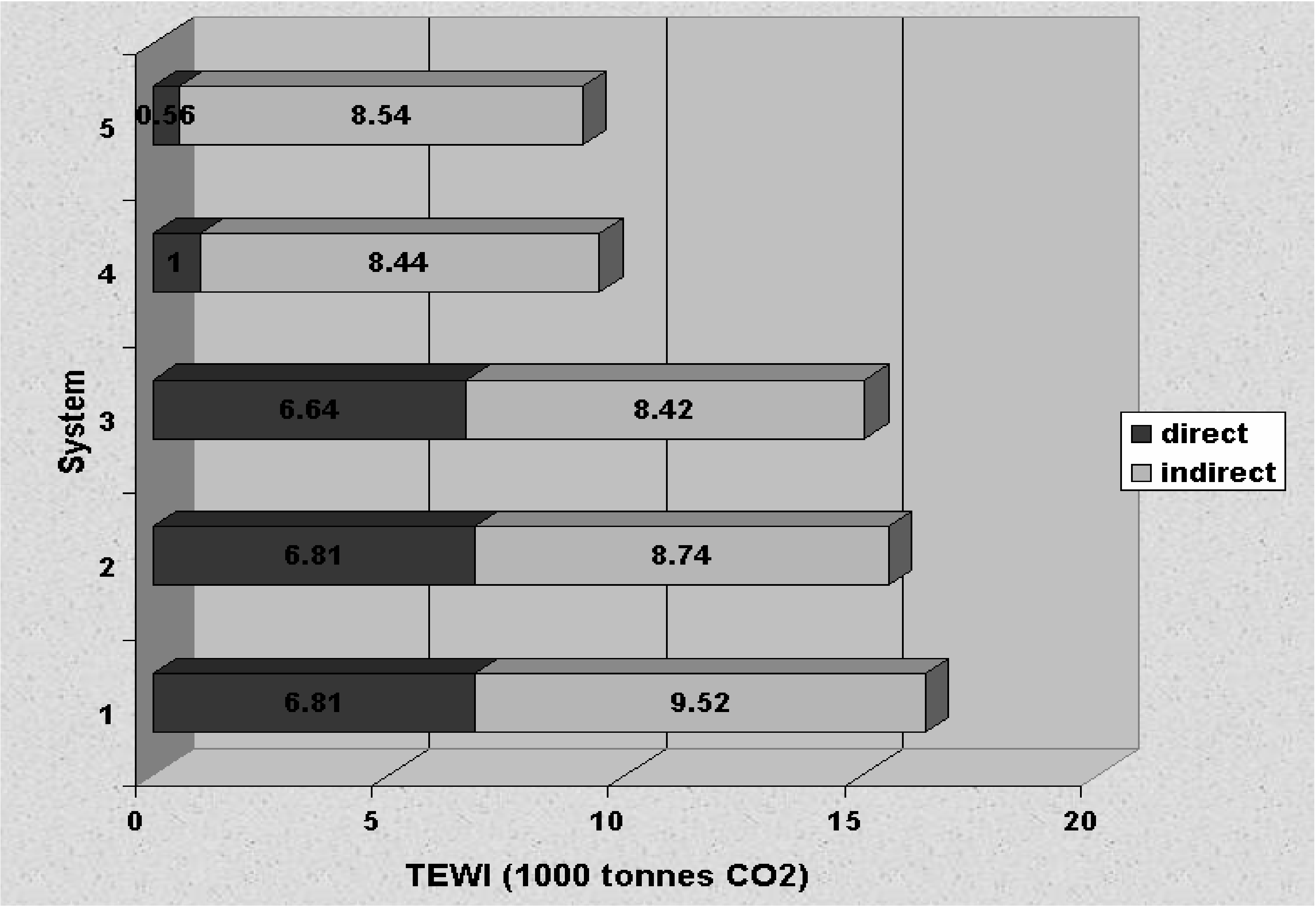
Alternate System Designs, contd.

- Secondary loop assumptions
  - Remote central chillers refrigerate intermediate fluid (brine) which is pumped to cases, etc.
  - Brine loops connect chillers to cases
    - four chillers each serving separate loop (-30, -18, -7, & -1 ^{o}C)
    - enhances overall system efficiency but adds cost
  - Evaporative condensers
  - Refrigerant charge is 225 kg, R507A

TEWI Comparison – Supermarket Refrigeration

System	Charge (kg)	Annual refrigerant loss (% charge)	Annual Energy (kWh)	TEWI (tonnes of CO_2)		
				Direct	Indirect	Total
1 - Multiplex DX w/air-cooled condenser	**1,360**	**15**	**976,800**	**6,810**	**9,520**	**16,330**
2 - Multiplex DX w/evaporative condenser	**1,360**	**15**	**896,400**	**6,810**	**8,740**	**15,550**
3 - Low-charge multiplex DX w/evaporative condenser	**906**	**15**	**863,600**	**6,640**	**8,420**	**15,060**
4 - Distributed compressor DX w/water-cooled condensers and evaporative cooling tower	**405**	**5**	**866,100**	**1,000**	**8,440**	**9,440**
5 - Secondary Loop w/evaporative condenser	**225**	**5**	**875,200**	**560**	**8,540**	**9,100**
Results for site in Washington, D.C. – 15 year service life						

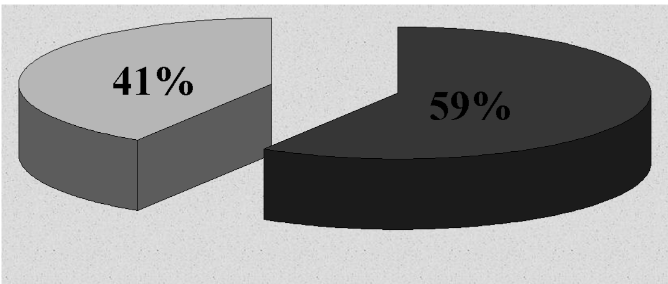
TEWI Comparison – Supermarket Refrigeration



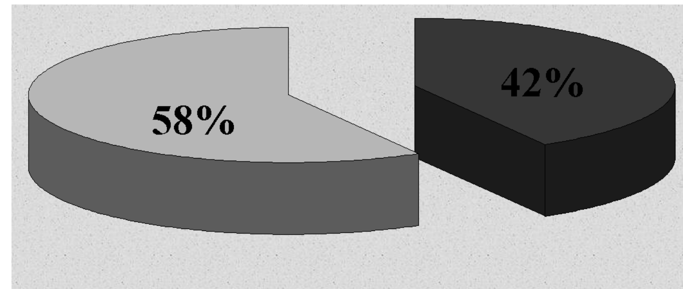
TEWI Comparison – Supermarket Refrigeration

- Direct effect about 40% of total TEWI for multiplex DX systems
- Replacing air-cooled condensers with evaporative can yield 8% energy savings
- Low charge system designs can reduce TEWI by 40% or more

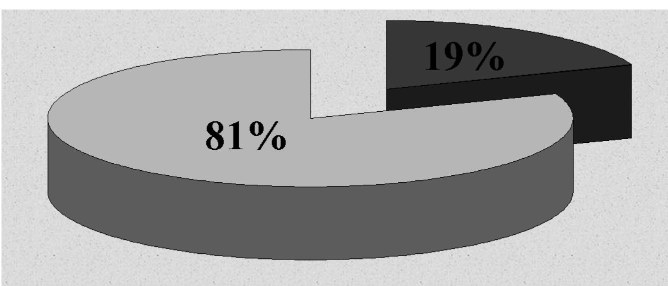
Sensitivity of TEWI to Leak Rate – Supermarket Refrigeration



Multiplex DX, 30% leak rate
TEWI = 23,150 tonnes CO_2



Multiplex DX, 15% leak rate
TEWI = 16,330 tonnes CO_2



Multiplex DX, 5% leak rate
TEWI = 11,790 tonnes CO_2

- Indirect (energy use) effect (light grey)
- Direct (refrigerant) effect (dark grey)

• Aggressive efforts to control refrigerant losses can minimize direct component of TEWI

• ***Energy efficiency becomes more important***

Conclusions – Unitary Systems

- Efficiency improvements provide best approach to future TEWI reduction
  - potential reductions of at least 9 tonnes of CO_2 emissions per unit over 15-year service life
- DOE future research focus on integrating heating, cooling, dehumidification, water heating functions to minimize energy use

Conclusions – Supermarket Refrigeration

- Direct effect still significant for multiplex DX systems (about 40% of total TEWI)
  - but aggressive efforts to minimize leaks can reduce direct portion to ¼ or less of total
- Evaporative condensing approaches can reduce CO_2 emissions by ~900 tonnes over system life
- Reducing energy use is best way to reduce TEWI for low-charge system designs
- DOE research focus on reducing energy use
  - reducing load and parasitic energy of display cases
  - improving system efficiency