"Understanding net benefits and cost for different energy efficient refrigeration design options "

Save the date: 22nd July 2020

Time: 15:00 CEST

Speaker: **Omar Abdelaziz, Ph.D.,**

Member ASHRAE, Assistant Professor of Thermofluids at Zewail City of Science and Technology

Moderator: Nigel Cotton
Twitter: @nigeldrcotton

#EERefrigeration20

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INDUSTRIAL DEVELOPMENT ORGANIZATION

KIGALI
COOLING EFFICIENCY PROGRAM

International Copper Association
Copper Alliance

Starting soon

Nigel Cotton
Moderator
@nigeldrcotton

Introduction: UNIDO- Dr. Fukuya Iino Ph.D.

The Kigali Cooling Efficiency program (K-CEP) through UNIDO* and ICA* has funded the "Assessment of incremental capital and operating costs for improved Energy Efficiency (EE) in domestic and commercial refrigeration" project. The study sets out to:

- Assess potential incremental capital and operating cost based on ongoing or planned projects related to EE improvements
- Assess respective markets in terms of barriers and advice on ways forward, offering inputs and recommendations
- Demonstrate the EE contributions to accelerate the climate benefits of the Kigali Amendment to phase down hydrofluorocarbons
- Provide Technical Assistance and field visits to companies producing domestic and commercial refrigerators
- Develop cost analysis for EE and refrigerant conversion

Twitter: @fukuyaiino

*International Copper Association (ICA)

*United Nations Industrial Development Organization

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Poll Question # 1

Please select the category that best describes your role:

a) Domestic refrigerator manufacturer
b) Commercial refrigerator manufacturer
c) OEM (compressors, heat exchangers, fans, motors, etc.)
d) R&D consultant
e) Academia

Why Refrigeration Equipment?

Global warming is accelerating faster than originally expected

The IPCC estimates that the global average temperature increase is likely to reach 1.5°C between 2030 and 2052 if we continue business-as-usual (BAU)

If temperature increase exceed 2°C, we will experience long-lasting or irreversible impacts

Global refrigerators stock is ~1.5 Billion consuming ~4% of global electricity

- HFCs and rapid urbanization will increase the share of buildings' GHG emission

Further innovation, design and engineering solutions are needed quickly and at scale to improve EE, optimize their utility, and enable lower emission energy sources (e.g. renewable energy)

“Assessment of incremental capital and operating costs for improved Energy Efficiency (EE) in domestic and commercial refrigeration”

The Project Guidance document includes:

- Methodology- Desk research, site visit and simulation studies.
- Manufacturers Development Index
- CERA software, Cost efficiency Curves
- Barriers
- Recommendations

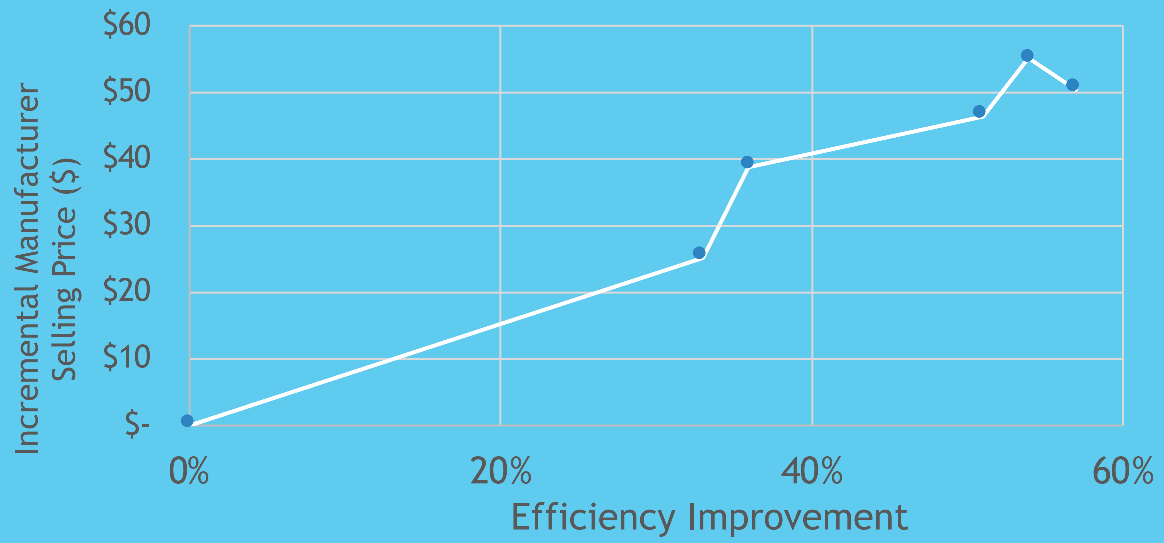
Manufacturer Development Index

In order to avoid revealing manufacturer’s proprietary information while presenting the study; the manufacturers were characterized using a Manufacturer Development Index (MDI) that accounts for:

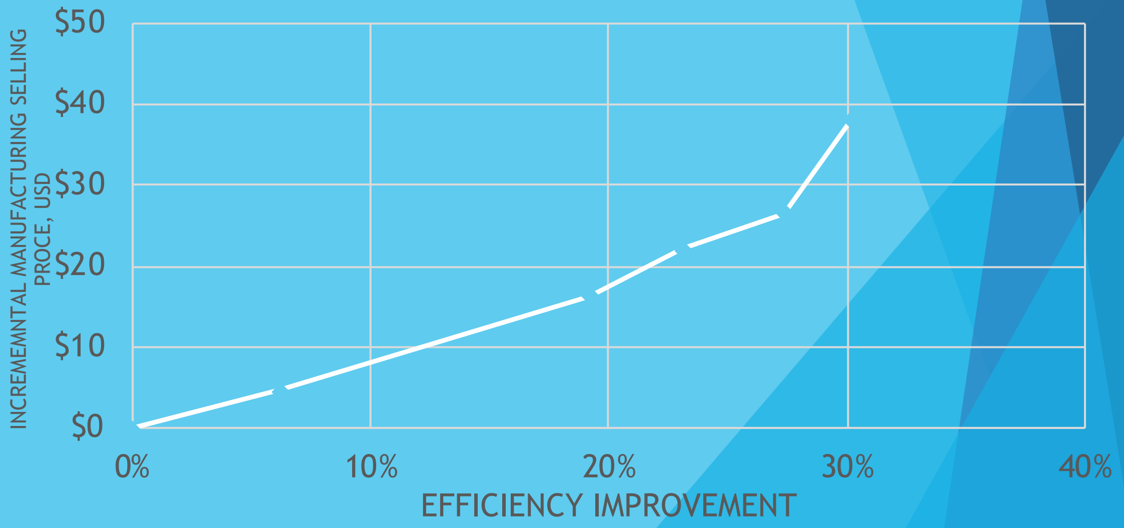
- Manufacturer development capacity (modelling capabilities, experimental facilities, and product development team capabilities and management)
- Manufacturer production volume (regional leadership, national leadership, medium scale manufacturer, small producing manufacturers)
- Manufacturer proximity to and relationship with component's OEM (access to components and the ability to work with the supplier)
- Market maturity (based on the consumer awareness, MEPS in place, and product competition
- Country's energy efficiency score (World Bank RISE index normalised to 10)

Impact of MDI on Net-Benefit of Energy Efficiency versus cost

MDI=0.534



MDI=0.814

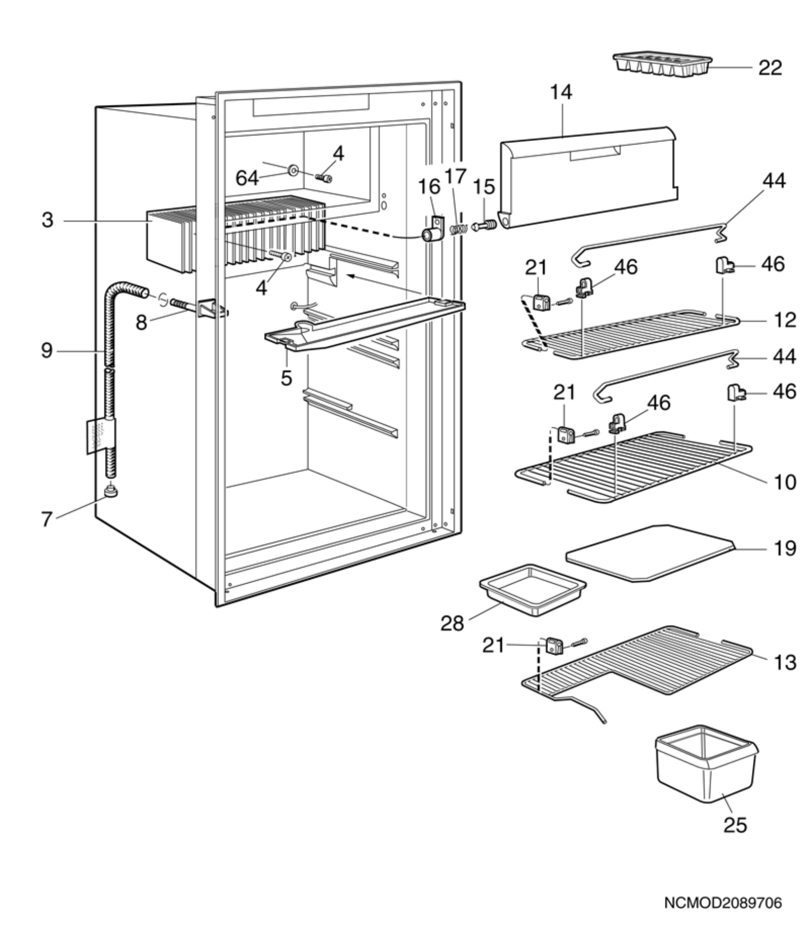


Reducing GWP depends on Refrigerant Choice, *Improving EE depends on Design Choice*

- We will be looking at HC-600a for domestic and HC-290 for commercial applications
- We will use the “UNIDO Assessment of incremental capital and operating costs for improved Energy Efficiency (EE) in domestic and commercial refrigeration” report to:
  - Understand potential EE technologies
  - Model the baseline along with EE technologies using CERA
  - Evaluate the net-benefit of energy efficiency versus price premium using the Cost analysis workbook to identify relevant energy efficient design options and their associated initial and operating costs
- Available @ https://www.unido.org/cera

Refrigerant Choice for Domestic and Commercial Refrigerators

	Domestic		Commercial	
Refrigerant	HFC-134a	HC-600a	R-404A	HC-290
GWP	1360	1	4200	1
Safety Designation	A1	A3	A1	A3
Energy Efficiency	NA (baseline)	~3%better	NA (baseline)	5 – 10% better
Safety Implications	None	Precautions necessary for design, manufacture, servicing and disposal	None	Precautions necessary for design, manufacture, servicing and disposal
Design Issues	None	Reduce leakage and ensure no sparks can ignite leaked refrigerant	None	Reduce leakage and ensure no sparks can ignite leaked refrigerant
Cost Difference	NA (baseline)	On par or cheaper	NA (baseline)	On par or cheaper
Service and Maintenance	None	Trained technicians and special equipment to handle flammable gas	None	Trained technicians and special equipment to handle flammable gas
End of Life	Must be recovered and destroyed or recycled	safe venting or recovery	Must be recovered and destroyed or recycled	safe venting or recovery
Prospects for future use and availability	Phased out in EU; Kigali amendment to the Montreal Protocol phase-down of HFCs		Phased out in EU; Kigali amendment to the Montreal Protocol phase-down of HFCs	



https://www.caravansplus.com.au/images_tiff/2014/RM2555-Black-Cabinet.gif

Component and Design Choices

Cabinet:

- Dimensions and Insulation
- Gasket and heat leaks
- Anti-sweat heaters

Sealed System:

- Compressor
- Evaporator
- Condenser
- SLHX

Controls:

- Mechanical
- electronic

Example EE replacement options for Domestic Refrigeration (Found from Literature)

Option #	Change from previous option	Energy Consumption, kWh/yr.	% Energy Savings from baseline	Incremental Cost from Baseline (USD)†
Baseline	Baseline	580.7	0%	0
1	Increase insulation to 60mm	529.6	9%	1
2	Increase freezer insulation to 80mm	405.9	30%	1.5
3	Use compressor with EER=6.0	202.2	65%	48
4b	Increase insulation to 90mm in freezer and 65mm in fresh-food, and optimized gaskets	138.3	76%	53
5b	Maximum VIPs	95.6	84%	65
6b	Use compressor with EER=6.57	86.1	85%	225

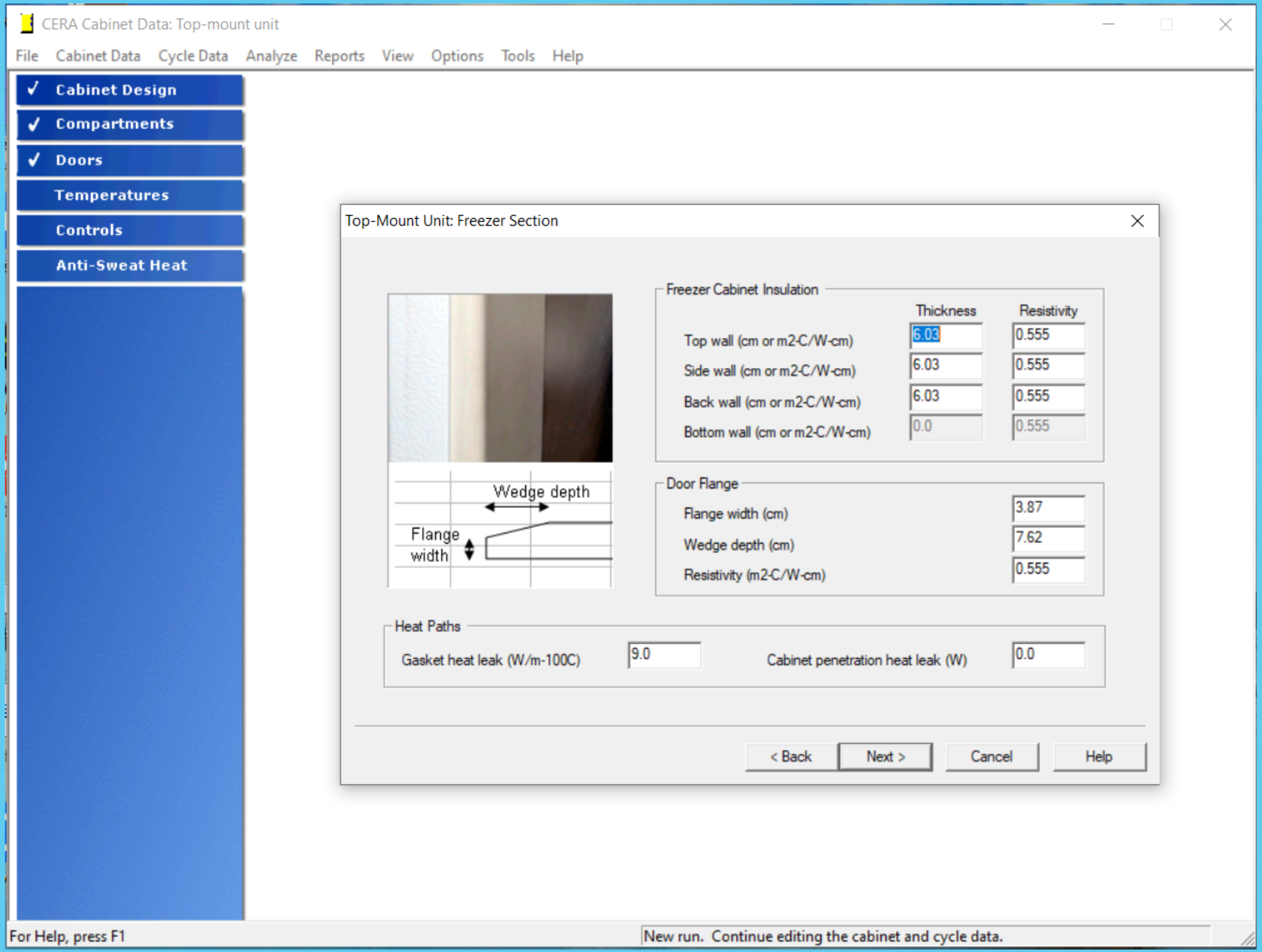
Example Commercial Refrigerator EE Options-20-30 options found, See Guidance Document

Option	Potential EE improvement	Indicative additional cost
Anti-fogging glass	Minimal	<5%
Improved cabinet air flow	4%-15%	neg.
Energy efficient fan/motors		
- EC fan motors	10%	+15%
- variable speed	10%	+15%
- optimised fan blades	5%	Neg.
Improved gaskets	15%	$30
Compressors	30-40%	
Expanders	30%	n/a
Cabinet lighting => LEDs	50% on lighting	<0%

Commercial Refrigerator EE Options
See Guidance Document

Option	Potential EE improvement	Indicative additional cost
- occupancy sensors	10%	<0%
Defrost techniques	5%- 10%	Neg
Controls	2%-40%	\$40-\$400
Reducing head pressure	2 – 4% per 1 K reduction	Various
Heat exchanger optimisation	0 to 40%, fn baseline	Neg
Vacuum insulated panels (VIP)	15%	\$400/m^2
Heat pipes	12%	n/k
Leak minimization	15%-20%	10%
Higher efficiency refrigerant	See RTOC 2014, 2018	+/-
Nanoparticles in refrigerant	20%	\$20 – 100

Introduction to CERA modelling tool

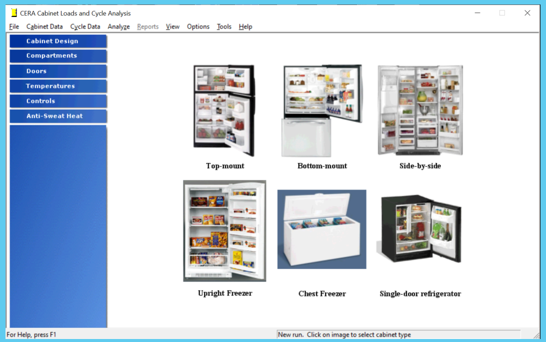


- Initially developed by US EPA/LBL then DOE
- Now adopted by UNIDO/K-CEP
- CERA is a dynamic model which uses physical dimensions and engineering data (compressors, HXs, fans, foam, etc.)
- Dialogue boxes are used to build your existing refrigerators using your own data
- The baseline models are then calibrated against experimentally measured performance to ensure that it is a true representation of the performance.
- Next, a series of design modifications are made to achieve improved EE

CERA Software and Running Simulations

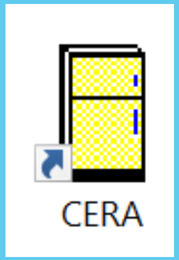
- Allocate time and engineering staff to project
- Download CERA @ https://github.com/unido
- Download Cost Analysis workbook @ https://github.com/unido
- Gather data using questionnaire
- Run simulation base case
- Replace components
- Re-run simulation to verify improvements in EE.

Manufacturer Steps using CERA to build a Cost Efficiency Model



- Gather all required engineering data (dimensions, performance curves, etc.)
- Contact OEMs for EE technology options

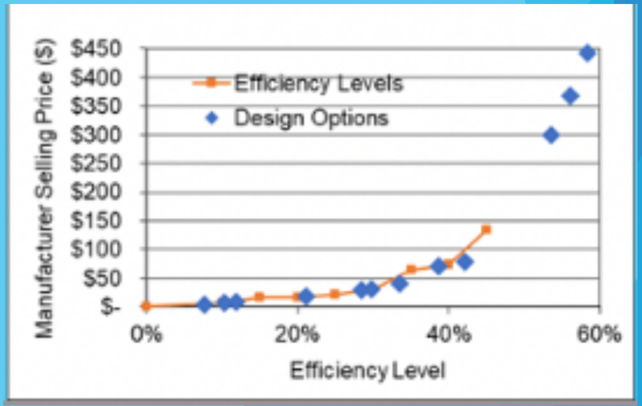
Perform equipment energy modeling (CERA)



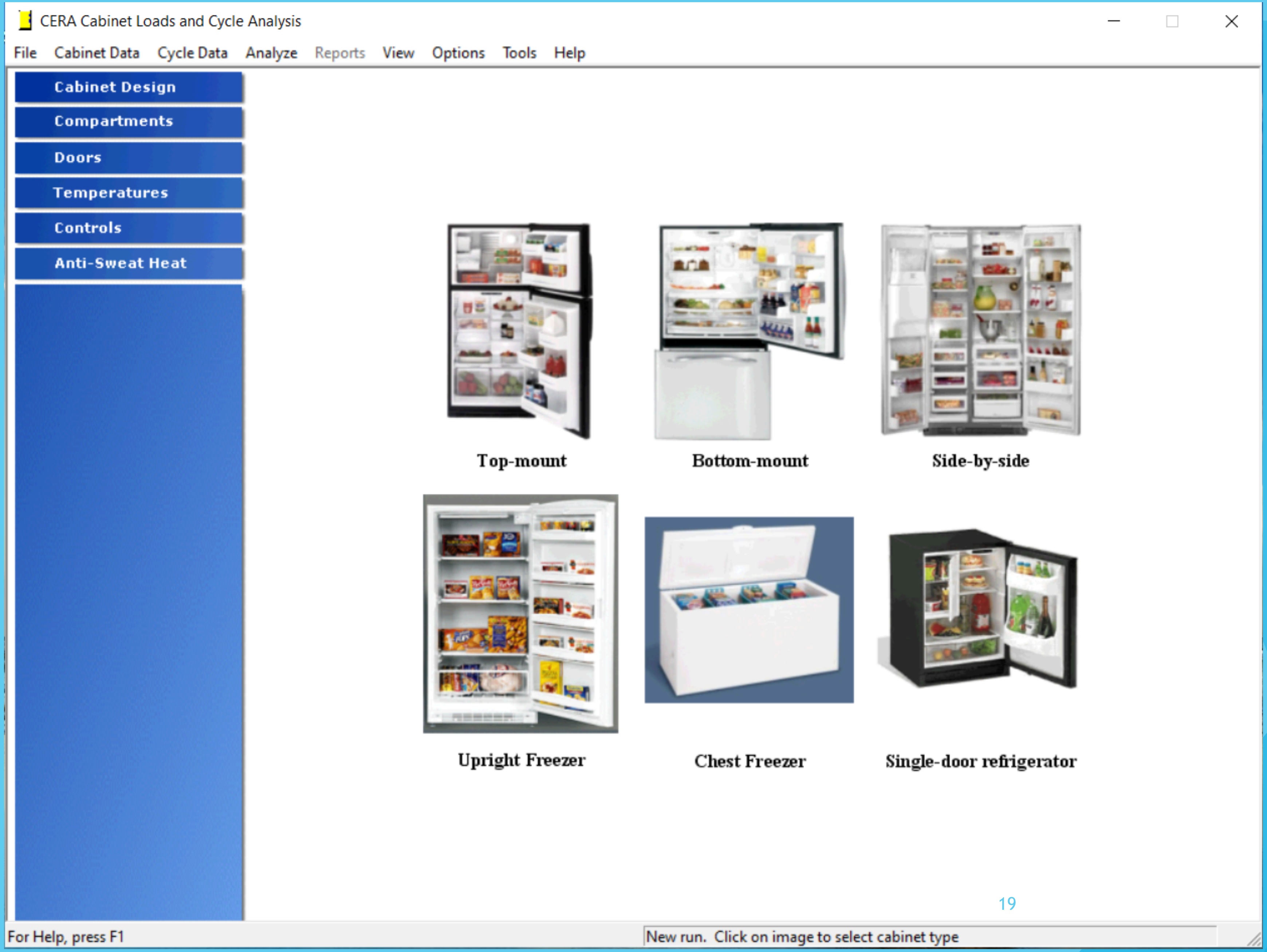
Estimate cost premium
- TSDs (U.S. DOE, Ecodesign)
- Open literature
- Contact with OEMs

Incremental cost estimates
- Capital (amortized)
- Operating

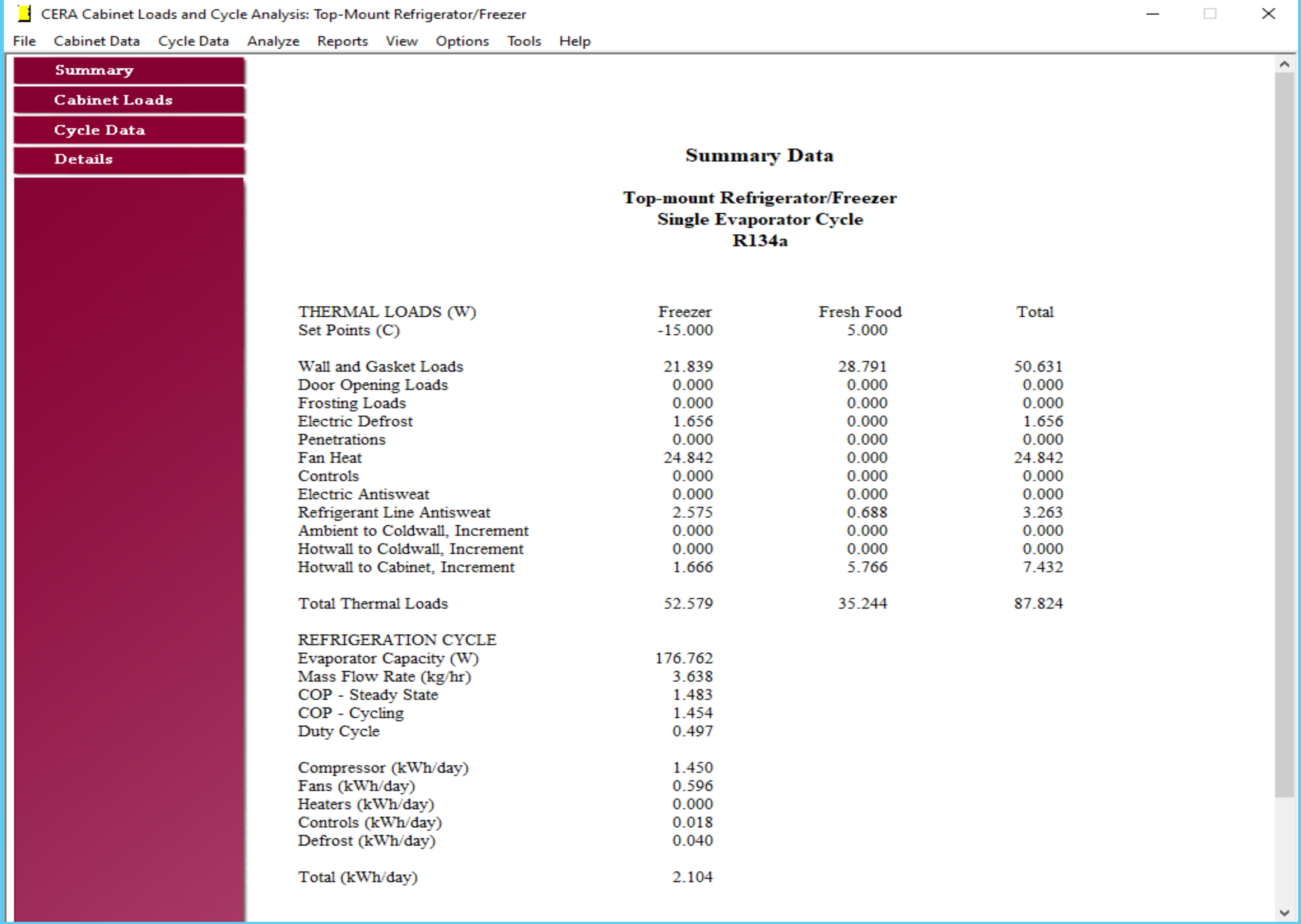
Obtain cost efficiency curves



Time to build your own model



Run Simulation and Obtain Results



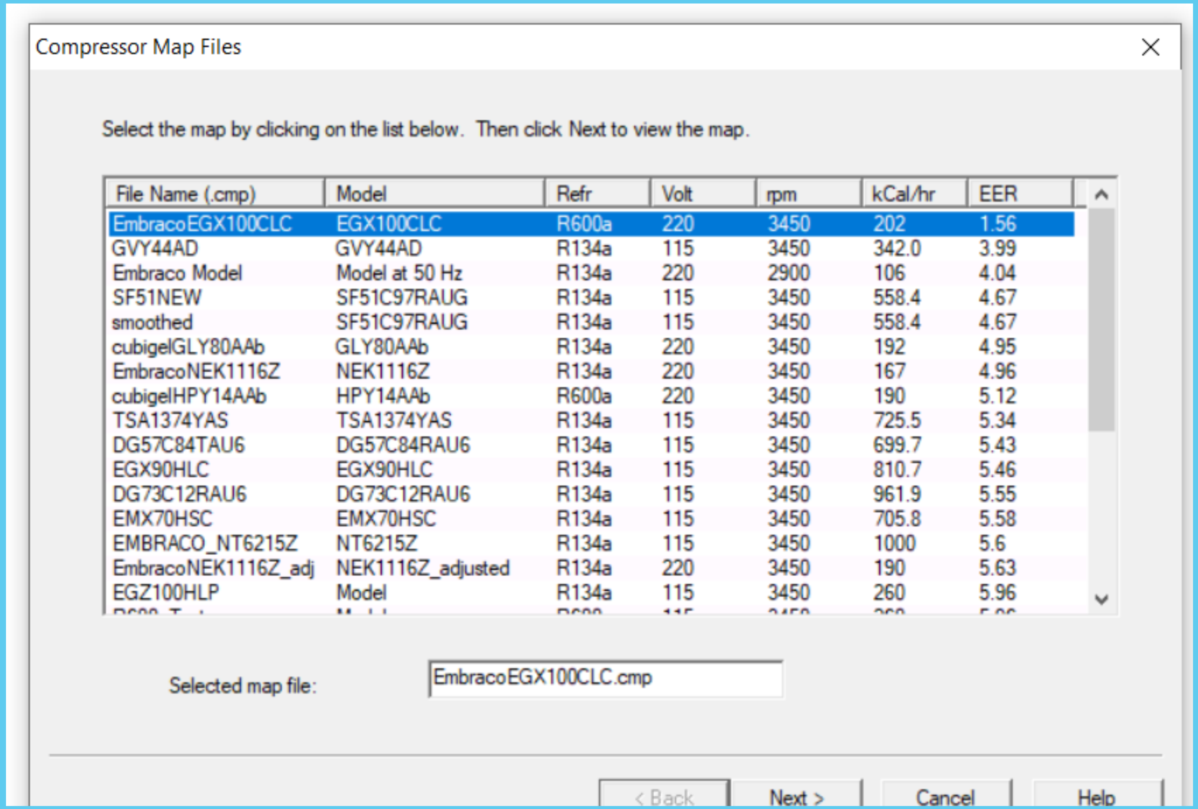
Summary Data

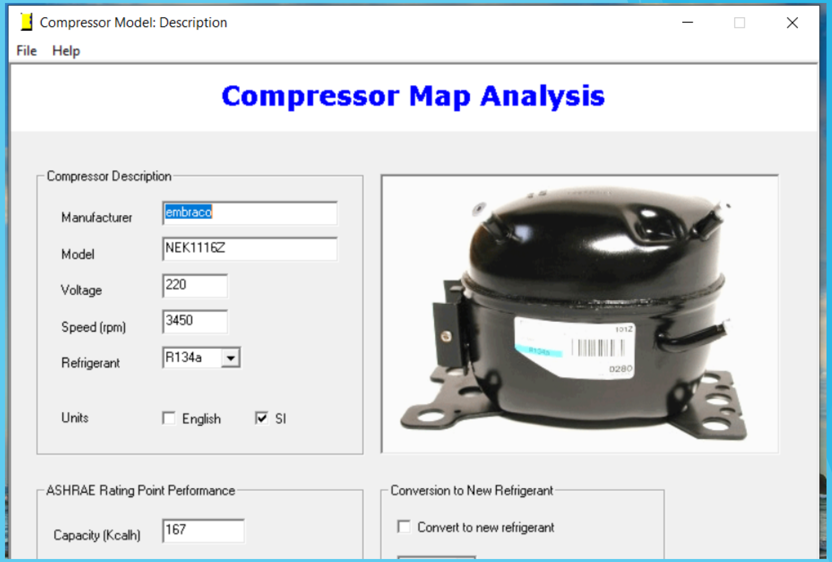
Top-mount Refrigerator/Freezer
Single Evaporator Cycle
R134a

THERMAL LOADS (W)	Freezer	Fresh Food	Total
Set Points (C)	-15.000	5.000	
Wall and Gasket Loads	21.839	28.791	50.631
Door Opening Loads	0.000	0.000	0.000
Frosting Loads	0.000	0.000	0.000
Electric Defrost	1.656	0.000	1.656
Penetrations	0.000	0.000	0.000
Fan Heat	24.842	0.000	24.842
Controls	0.000	0.000	0.000
Electric Antisweat	0.000	0.000	0.000
Refrigerant Line Antisweat	2.575	0.688	3.263
Ambient to Coldwall, Increment	0.000	0.000	0.000
Hotwall to Coldwall, Increment	0.000	0.000	0.000
Hotwall to Cabinet, Increment	1.666	5.766	7.432
Total Thermal Loads	52.579	35.244	87.824

REFRIGERATION CYCLE	
Evaporator Capacity (W)	176.762
Mass Flow Rate (kg/hr)	3.638
COP - Steady State	1.483
COP - Cycling	1.454
Duty Cycle	0.497
Compressor (kWh/day)	1.450
Fans (kWh/day)	0.596
Heaters (kWh/day)	0.000
Controls (kWh/day)	0.018
Defrost (kWh/day)	0.040
Total (kWh/day)	2.104

- A summary sheet can be run for each change or series of changes
- Cross checks can be made for total kWH/day etc.





Option to amend data to known performance

Choose a component to replace and use your own data if desired

Repeat Simulation

CERA Cabinet Loads and Cycle Analysis: Top-Mount Refrigerator/Freezer

File | Cabinet Data | Cycle Data | Analyze | Reports | View | Options | Tools | Help

- Summary
- Cabinet Loads
- Cycle Data
- Details

Summary Data

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Total (kWh/day)	2.104

Live Demo

Results –Incremental Operating Costs

Energy Efficiency Cost Guidelines – IOC for Domestic Refrigerators

Technology	MDI									
	EE improvement potential					IOC				
	0.814	0.566	0.534	0.52	0.212	0.814	0.566	0.534	0.52	0.212
Change insulation Thickness	4%	5%	9.50%			3.72	2.5	17	6	
Change of air circulation									3	
High efficiency evaporator fan	16%	11%	18.50%			-1.21	5	6	4	
Inverter compressor	12.50%	29%	30%			-3.54	16.35	45	5	
Use defrost timer	2.75%					3			1	
Optimize Gasket		6.50%					6.5		1	
Refrigerant switch							-1.5			0.22
Improved Compressor	11.50%	25.50%	6.50%			1.44	1.05	6.5		6.375
Improved Evaporator	12.50%		3%			3.89		-4.65		
Improved Condenser	4%									
High Efficiency Condenser Fan	11%					0.71				

Energy Efficiency Cost Guidelines – IOC for Commercial Refrigerators

Technology	MDI							
	EE				IOC			
	0.814	0.776	0.534	0.52	0.814	0.776	0.534	0.52
High Performance IGU for doors		23%	33%			22	20	
Use High Efficiency Compressor		8%				-5		
increase insulation thickness		5%				0.76		6
Optimize Gasket		1.50%				4		1
MCHX		2%				5		0
Smart controller	12.50%		5%	10%	10.71		6	22.5
VIP	4%				5.33			35
ECM motors and improved fan designs	26.50%	4%			33.53	2		
Digital controller with IOT	30%		30%		39.74		55	
Use LED lighting	2%				3.14			

Increasing insulation thickness

Production line change	Cost for different Manufacturers (if any) in 1,000,000 USD					
	MDI					
	0.814	0.776	0.566	0.534	0.52	0.212
Bending Machine			\$0.85 – \$2.5			
Moulds	\$4.1 for the complete product lines	<\$0.05 per base model	\$0.5 per base model	<\$0.05 per base model	<\$0.05 per base model	

Production line change	Cost for different Manufacturers (if any) in 1,000 USD					
	MDI					
	0.814	0.776	0.566	0.534	0.52	0.212
Welding jigs		\$3 each	\$9 ×6			

Refrigerant Conversion IOC

MDI	0.814	0.776	0.566	0.534	0.52	0.212
Production Lines	2	2	2	1	1	1
Production line change	Cost for different Manufacturers (if any) in 1,000 USD					
HC detectors	$\$35\times4$	$\$13.6\times4$	$\$15\times9$	$12	$\$12.5\times2$	
Portable HC detectors	$\$1.25\times4$	$\$8.1\times4$				$\$2.5\times5$
He charging and recovery	$\$20\times6$	$\$51\times3$			$45	
Safety systems	$195	$121.43	$218	$50.8	$52	$70
Charging machines	$\$120\times4+\$70\times1$	$\$43\times4$	$\$50\times4$	$92.5	$65	$40
Storage and distribution	$222		$90		$5	$45
Transfer pumps		$\$6.5\times2$	$\$27.6\times2$		$\$10\times2$	
Ultrasonic welding	$\$27\times5$		$\$30.5\times4$		$25	
Accessories for charging unit					$10	
Refrigerant extraction unit	$\$13.2\times4$	$\$9.4\times2$		$20	$5	
Calibrated leaks		$7.8			$2.5	
Vacuum pumps	$\$16\times8$			$\$8.1\times6$		
Upgrade functional testing	$\$116.7\times3+\$84$			$55		$35
Installation, commissioning, and training		$19.8	$20	$11.5	$10	$5
After sales			$30			
Total	$1,982	$592.475	$870.1	$290.4	$264.5	$207.5

Poll Question # 2

a) In your opinion, which technology option would be the most relevant to improve your refrigerator's energy efficiency?
   a) Changing to a more efficient compressor
   b) Reduce door gasket heat leaks
   c) Changing the refrigerant
   d) Changing insulation thickness and type
   e) Replacing the evaporator fan to more efficient fans

Emissions Reduction

$$ER = [E_r + E_{ind}]_{Baseline} - [E_r + E_{ind}]_{project}$$

Emissions, tCO_{2eq}	MDI		
	0.814	0.566	0.52
$[E_r]_{Baseline}$	16,529	29,443	111,622
$[E_{ind}]_{Baseline}$	278,000	357,230	2,902,394
$[E_r]_{project}$	3,813	22	28
$[E_{ind}]_{project}$	154,452	321,507	2,401,029
ER	136,263	65,145	612,959
Max EE - ER	157,675	190,175	1,077,005

- Market Barriers

Market Barriers – Domestic
Examples See Guidance Document for full list

- Consumer behaviour:
  - Driven mainly, or exclusively, by first cost
    - Not aware of EE benefits to themselves or society
    - Energy labels, if available, are not well appreciated (small annual electricity cost) ➔ **Need for educational campaigns**
  - Consumers are looking for more reliable refrigerators (resilience over EE) in areas with unstable electric grid or limited electricity penetration
- Lack of MEPS in some regions
  - Need to comply to different regional MEPS which are not harmonized and required different testing methodologies
- Lack of governmental financial incentives for EE appliances
  - Electric subsidies, lower electricity rates, result in increased payback periods and as such have adverse impact on EE adoption

Market Barriers Commercial
Examples See Guidance Document for full list

- Sales controlled by business-to-business (B-2-B) sales
  - Driven by client's specifications/guidelines and test methods → more progressive than national or regional MEPS, if they exist
  - Customer consolidation rendered the commercial refrigerator market a "buyers" market → increased client purchase power → smaller margins but guaranteed volumes
  - Manufacturers cannot afford the increase of $20 in components unless the B-2-B customers modify their specifications or accept the higher price
- Non-institutional customers are primarily driven by first cost and have limited appreciation of the lifecycle monetary and societal benefits of EE
  - Acceptable payback is 18 months
  - Some shop owners put electricity sub meters ($20 per device) on their vending machines

Poll Question #3

a) Beyond cost, which barrier is the most important to overcome?
    a) Imports from large overseas manufacturers
    b) Lack of awareness about the benefit of energy efficiency
    c) Lack of financial support for design and development

What the participating companies said:

“The guidance is insightful and has given us direction moving forward. GETS is interested in further training workshops and webinars”. Uganda: GETS

Lebanon: Lematic: “the recommendations in the report are very useful”.

“We are evaluating the software and looking for support to increase our engineering capacity”. Guatemala: Fogel

“We are exploring the suggested actions with emphasis to improve the energy efficiency of our systems”. Ecuador: Indurama

“Our first step to implementation of the guidance is to source high-efficient compressors” Morocco: Manar

Where to download resources- how to get further assistance.

Report https:www.unido.org/cera

Software https://github.com/unido

Brochure https:www.unido/cera

Webinar Archive: https://www.ashrae.org/technical-resources/supplier-provided-learning/supplier-webinars

Further Assistance:

Fee Paid Technical Support-Omar Adelaziz : omar.abdel.aziz@gmail.com

General Assistance- Nigel Cotton: nigel.cotton@brentwoodtech.co.uk

Future Project Enquires:

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UNIDO- Department of environment: environment@unido.org

International Copper Association- Pierre Cazelles: pierre.cazelles@copperalliance.asia

Please contact us if you are interested to participate in K-CEP Phase 2 Projects

Q&A

Please feel free to use the questions box to ask your questions

Due to the large number of attendees please provide only written questions

See right hand side dialogue box

Closing Statement

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Thank you for attending

You will shortly receive an email from ASHRAE with details of where to find all the information related to this webinar.

Report https:www.unido.org/cera

Software https:github.com/unido

Brochure https:www.unido/cera

Webinar Archive: https://www.ashrae.org/technical-resources/supplier-provided-learning/supplier-webinars

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