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DECK REFRIGERATION SYSTEM USING PROPANE AS REFRIGERANT IN A BOTTLE COOLER

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SCOPE

The **Complete Refrigeration System** shortly described here is the result of a Collaborative Project. The product was field tested during the last summer Olympics Games, Athens, 2004.

In the domain of small commercial appliances, manufacturers of Bottle Coolers Cabinets face troubles with **on-site maintenance** and challenges with **environmental impact**.

Development of an inovative cooling system has been based on the 3 mains **objectives**:

- system easier to handle;
- energy efficiency improvement;
- environmently friendly.

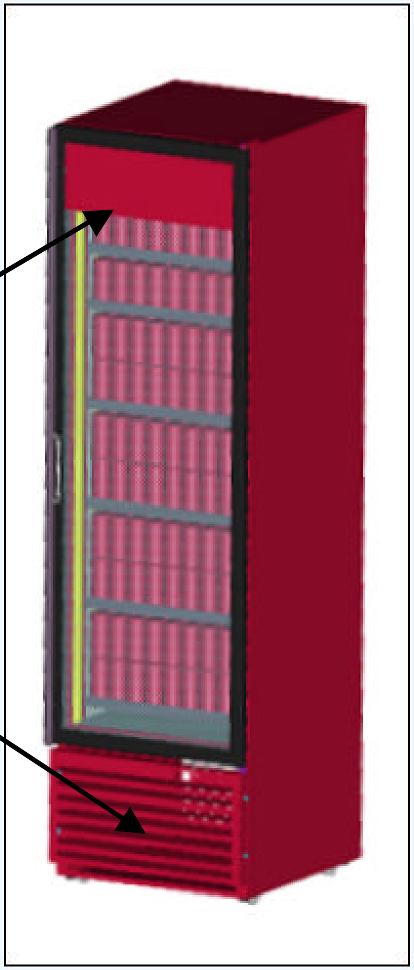
DECK SYSTEM

System easier to handle:

Traditionally, a refrigeration system in a cabinet is split into two sub-assemblies:

- evaporating unit

- condensing unit

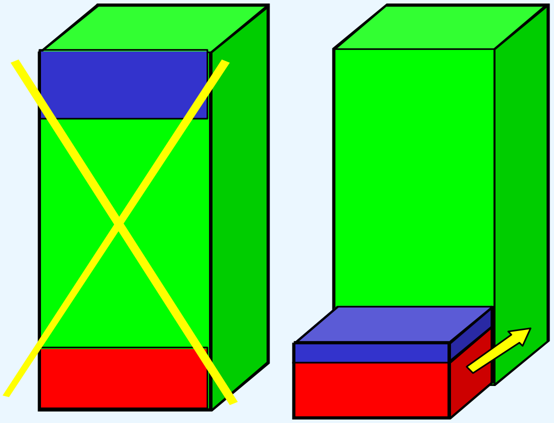


Difficult service at the point of sale.

DECK SYSTEM SOLUTION

System easier to handle:

- refrigeration module;
- plug-in type unit;
- replacing the deck instead of the cabinet;
- standardization opportunity.



DECK SYSTEM

Means to Improve Energy Efficiency:

- choice of refrigerant;
- optimization of electrical motors efficiency;
- air flow optimization.

DECK SYSTEM

Refrigerant Selection: HC vs HFC

Refrigerant	R134a	R152a	R290 (Propane)	R600a (Isobutane)	RC270 * (Cyclopropane)
Latent Heat of Vap. @ 40 ^{0} F (Btu/lbm)	84.1	129.75	156.744	149.7	178.66
Vap. Specific Volume @ 40 ^{0} F (ft^3/lbm)	0.9523	1.657	1.3483	3.265	2.001
Vap. Specific heat @ 40 ^{0} F (Btu/lbm ^{0}F)	0.217	0.251	0.4507	0.395	0.3402
Vap. Viscosity @ 40 ^{0} F (lbm/ft hr)	0.027	0.0231	0.019	0.0175	0.0197
Vap. Thermal Conductivity @ 40 ^{0} F (Btu/hr ft ^{0}F)	0.0072	0.0068	0.01	0.0083	0.00795
Latent Heat of Cond. @ 100 ^{0} F (Btu/lbm)	71.2	115.48	132.924	133.1	159.63
Liq. Density @ 100 ^{0} F (lbm/ft^3)	71.942	54.03	29.578	33.38	37.45
Liq. Specific heat @ 100 ^{0} F (Btu/lbm ^{0}F)	0.359	0.434	0.6727	0.627	0.5823
Liq. Viscosity @ 100 ^{0} F (lbm/ft hr)	0.4114	0.376	0.222	0.35	0.3193
Liq. Thermal Conductivity @ 100 ^{0} F (Btu/hr ft ^{0}F)	0.0437	0.0565	0.0526	0.059	0.0755

** Data from National Institute of Standards and Technology (NIST REFPROP)*

Thermodynamic and transport properties of HC and HFC

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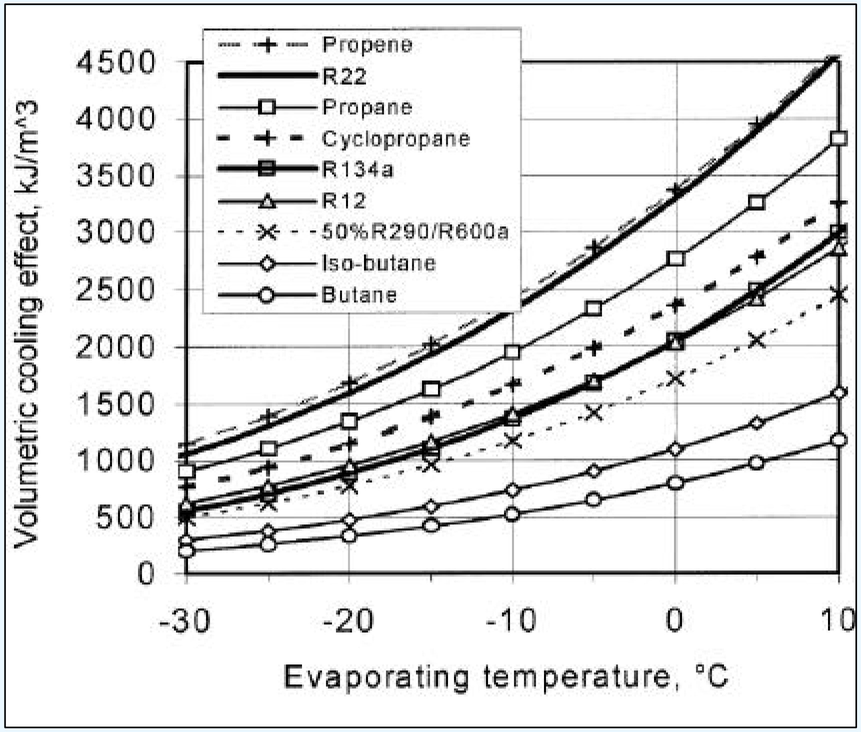
Refrigerant Selection:



Volumetric refrigerant capacity for the same cycle with 40°C cond. temp.
(From Granryd E. Hydrocarbons as refrigerant-an overview. Int. J. Refrig. 2001; 24; 15-24)

DECK SYSTEM

Refrigerant Selection:

HC vs HFC (R134a) main adavantages:

- thermodynamic and transport properties
  - higher latent heat of phase change;
  - lower viscosity;
  - higher thermal conductivity.

- cost savings:
  - smaller charge size (up to 50%) at lower cost ;
  - compliant with lower cost mineral oil.

- availability

DECK SYSTEM

Eco-friendly solution:

Table 1 Physical, Safety and Environmental Properties

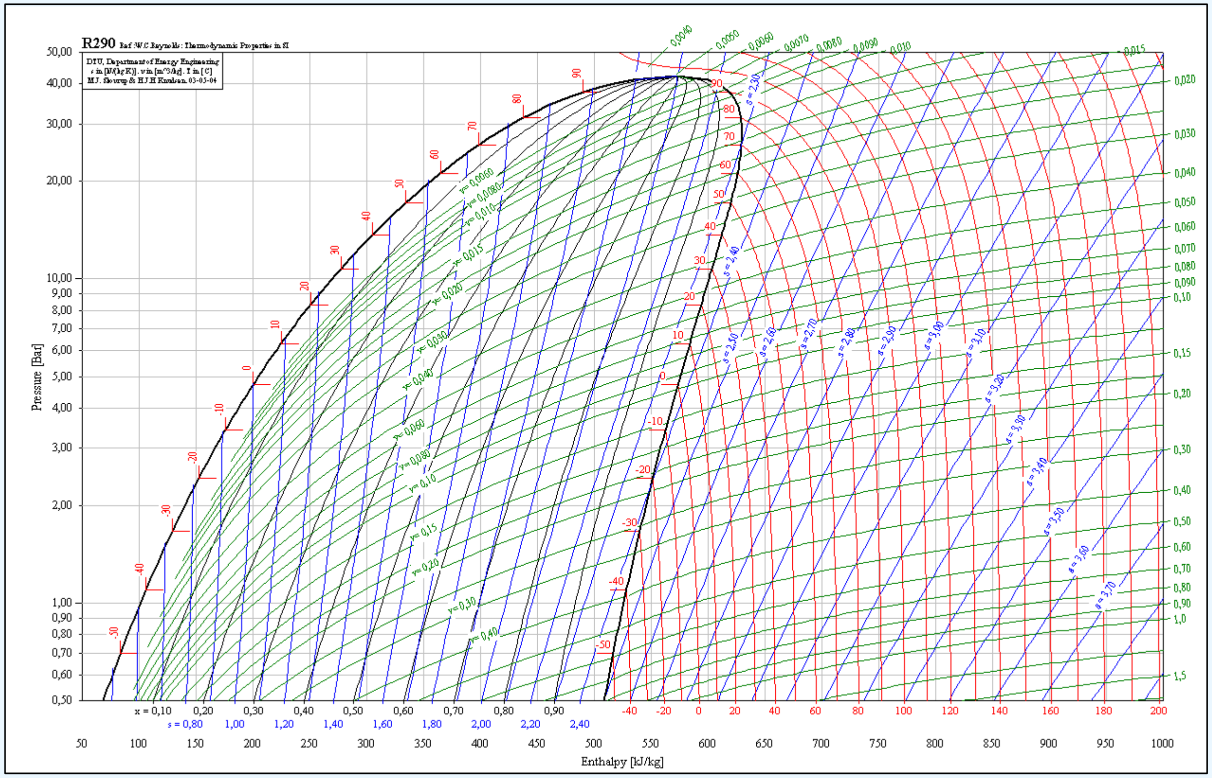
Refrigerant	R134a	R152a	R290 (Propane)	R600a (Isobutane)	RC270 (Cyclopropane)
Chemical Formula	CH_2FCF_3	CH_3CHF_2	$CH_3CH_2CH_3$	$CH(CH_3)_2CH_3$	$CH_2CH_2CH_2$
Molecular Mass	102.03	66.05	44.10	58.12	42.08
Critical Temperature (^{0} F)	214.00	235.90	206.20	275.00	257.40
Critical Pressure (psia)	589.00	656.00	616.00	529.00	809.00
Normal Boiling Point (^{0} F)	-15.00	-11.20	-43.80	10.80	-28.30
Lubricant	POE/PAG	N/A *	Mineral Oils	Mineral Oils	Mineral Oils
Stability	Stable	Stable	Stable	Stable	N/A
OSHA Permissible Exposure Limit (ppm)	1000	1000	1000	800	1000
Lower Flammability (% Volume in Air)	None	4.80	2.10	1.70	2.40
Heat of Combustion (Btu/lbm)	1806	7481	21625	21238	20800
Safety Group	A1	A2	A3	A3	A3
Auto Ignition Temperature (^{0} F)	1418	851	878	860	900
Atmospheric Life (yr.)	14	2	<1	<1	<1
Ozone Depletion Potential	0	0	0	0	0
Global Warming Potential (100 yr.) **	1300	140	20	20	20

*POE = Polyolester, PAG = Polyalkylene Glycol, * POE/PAG good candidates for R152a*
Safety Group = (A or B) lower and high toxicity respectively, (1,2, or 3) not flammable, low and high flammability
*** GWP for integrated time horizon, and based on 3500 kg CO_2 / kg of R11*

Data from National Institute of Standards and Technology (NIST REFPROP)

DECK SYSTEM

Selected Refrigerant: R290 (propane)



R290 Pressure-Enthalpy Diagram

DECK SYSTEM

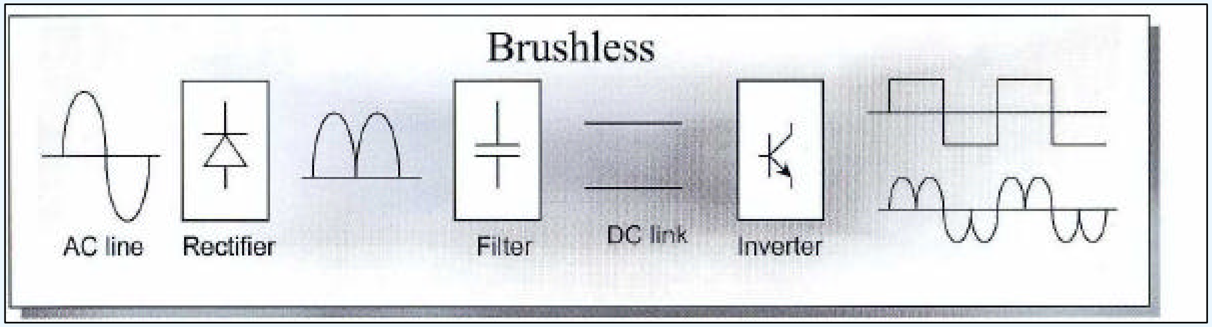
Electrical motors design optimization:

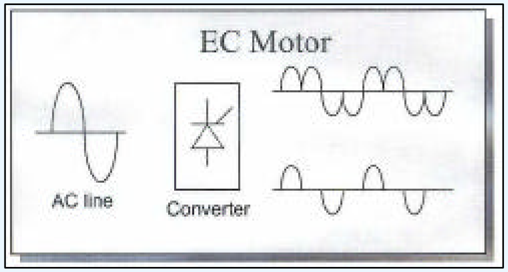
Fan motor:

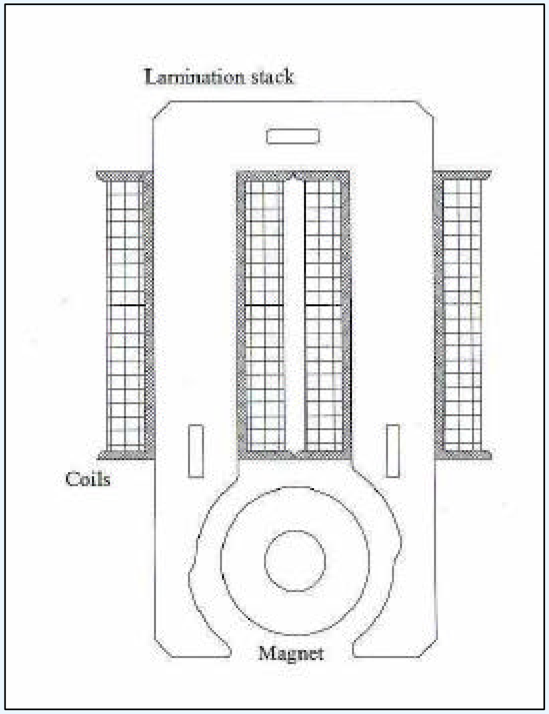
- electronically commutated synchronous permanent magnet;

- higher efficiency than shaded pole;

- lower component count than brushless.

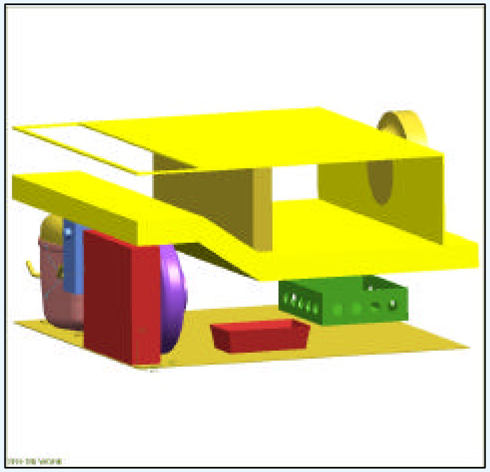


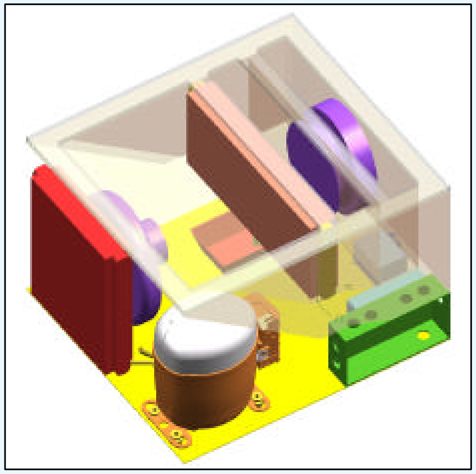


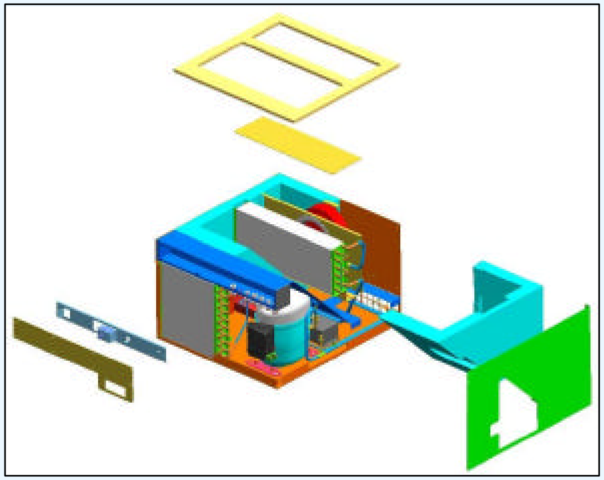


DECK SYSTEM DESIGN

CAD from the 1st layout to the definitive one...

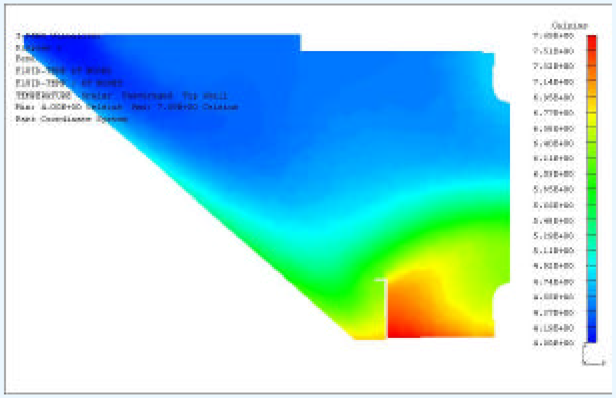




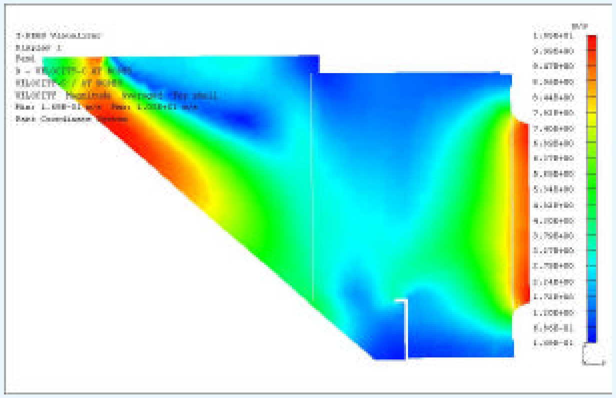


DECK SYSTEM

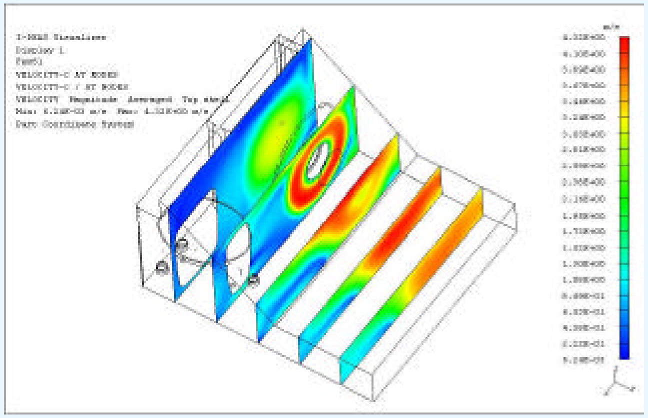
Air flow optimization:



Air velocity field



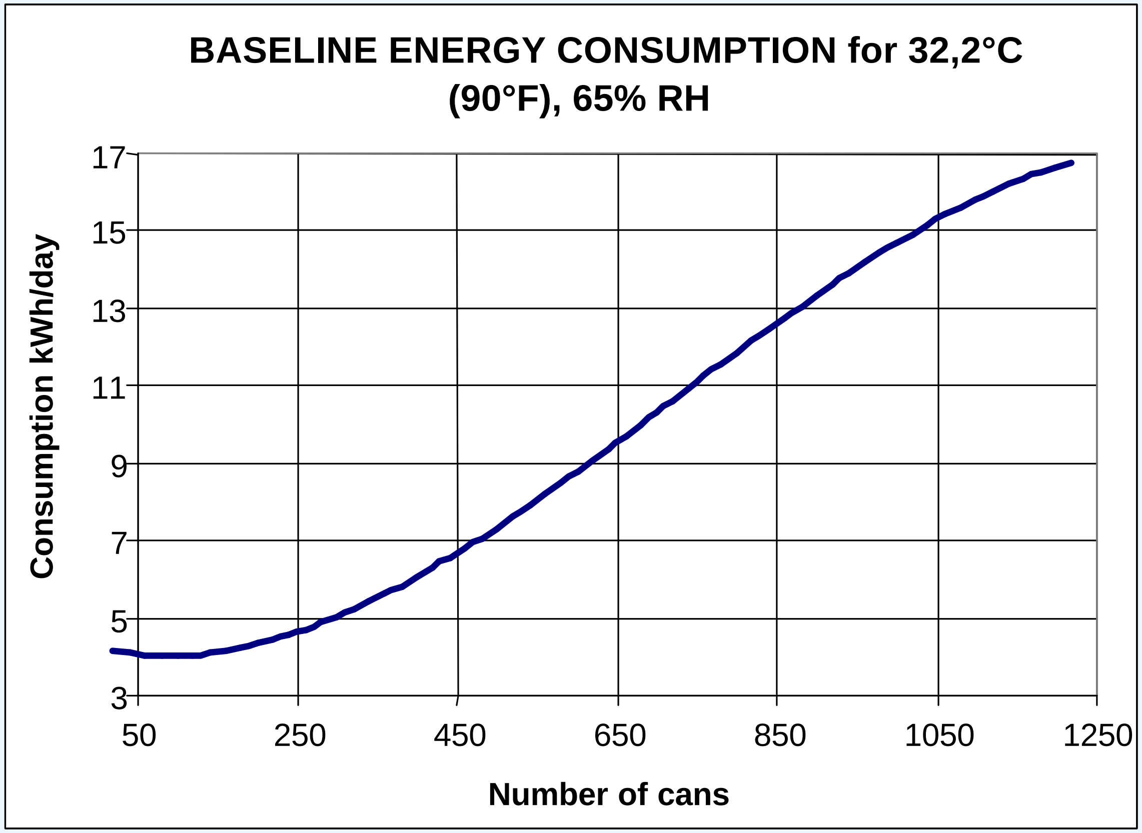
Air temperature field



LABORATORY TESTS

DECK SYSTEM TESTING

Experimental results:



Energy consumption of Bottle Cooler vs. Number of cans to cool

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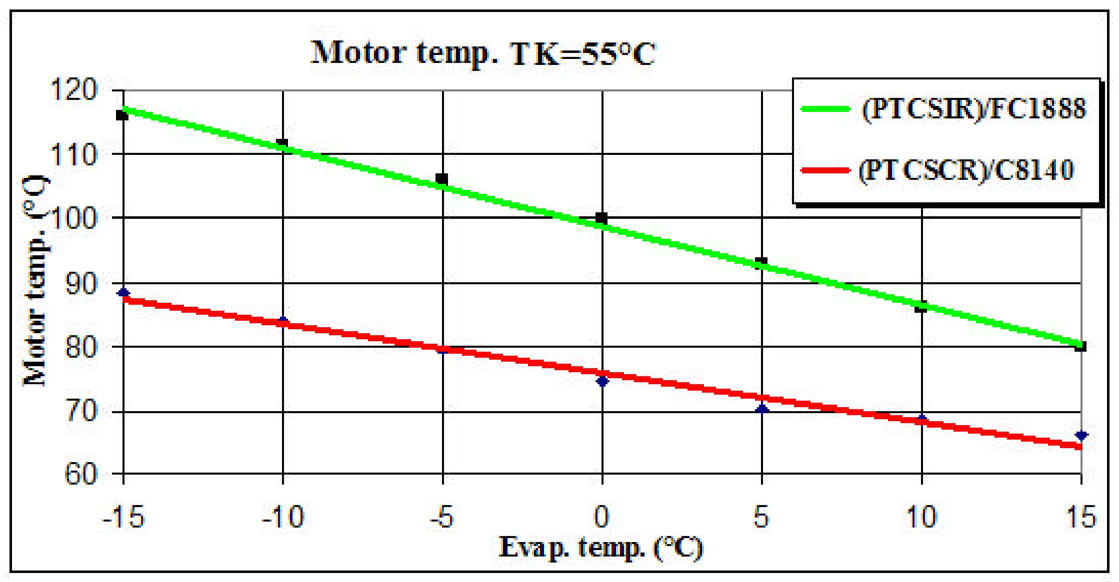
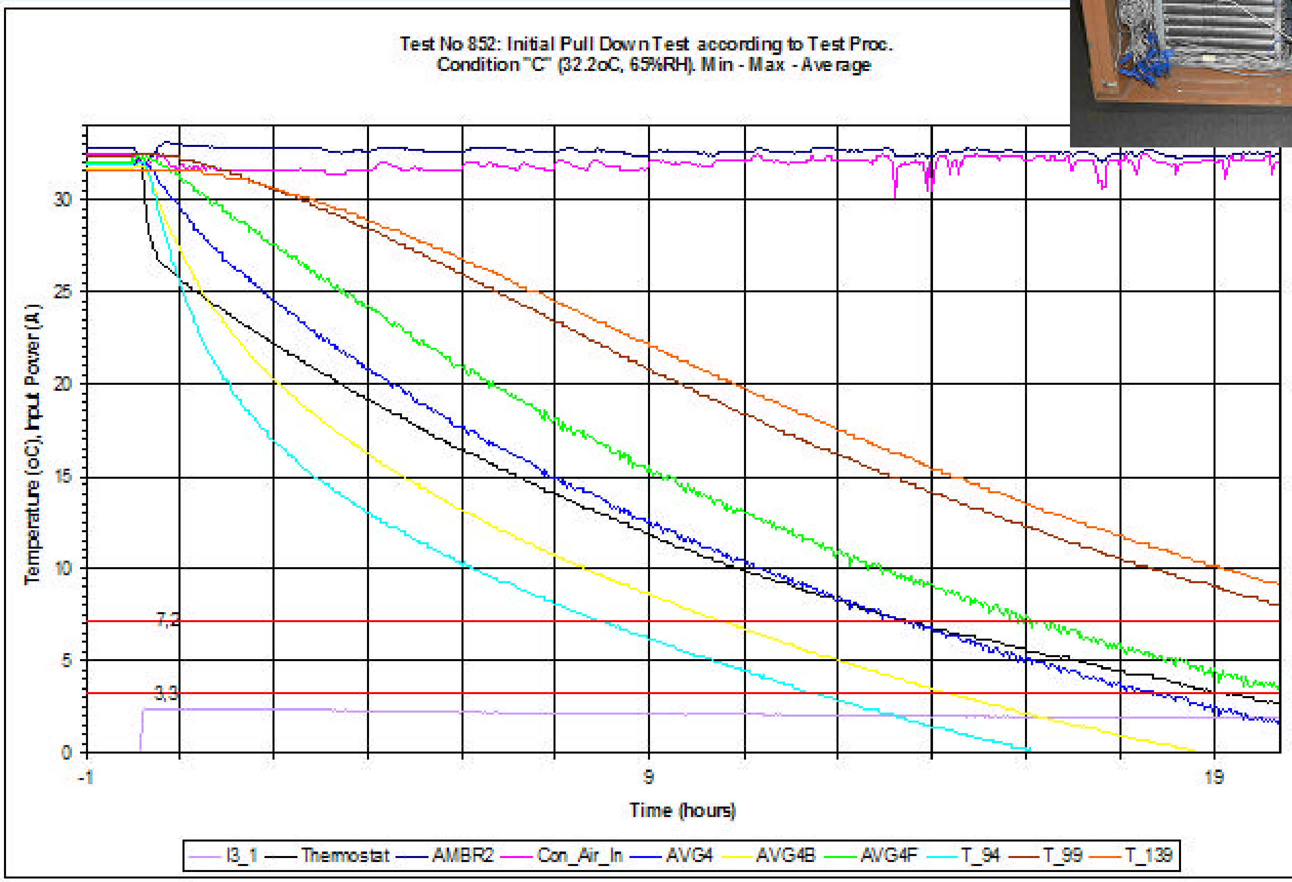
Increased motor cooling effect by using R290:



Compressor motor vs. evaporating temperatures for same condensing temperature by using R22 or R290

LABORATORY TESTS

Performance: Pull down test



LABORATORY TESTS

Energy efficiency measurements:

Cabinet size: 630 cans (US size)

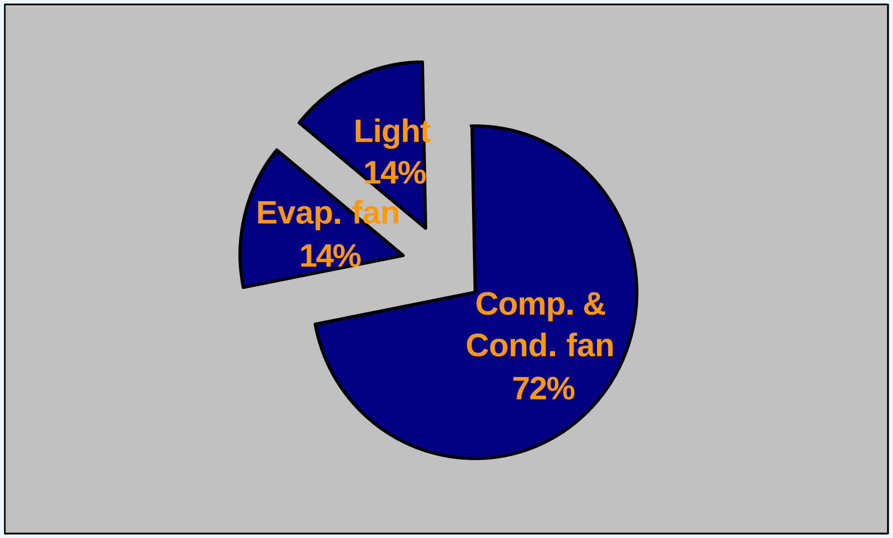
Baseline energy consumption

E = 9228 Wh/day

On/off cyle test

E = 6040 Wh/day

Ratio on/off = 0.49



Power Consumption Reduction: 35%

SYSTEM SAFETY

Safety measures:

Design:

- spark free design
- fully sealed system
- refrigerant charge limited (<150g)
- factory-built system

Standards:

- EC rules : Risk Analysis (FMEA), Public Area, LVD, PED, MD, EMC directive
- conformity with IEC60335-2-89
- conformity with IEC79-15

CONCLUSION

- A new Complete Refrigeration System using HC as refrigerant has been designed and integrated in a Bottle Cooler cabinet;
- Compactness and ease of handling as a plug-in peripheral unit are the main advantages of this HC system;
- A power consumption reduction of 35% at the same service rate was achieved by using this HC system;
- HC can be used safely as refrigerant in specialy designed factory-built systems in compliance with International Standards requirements.