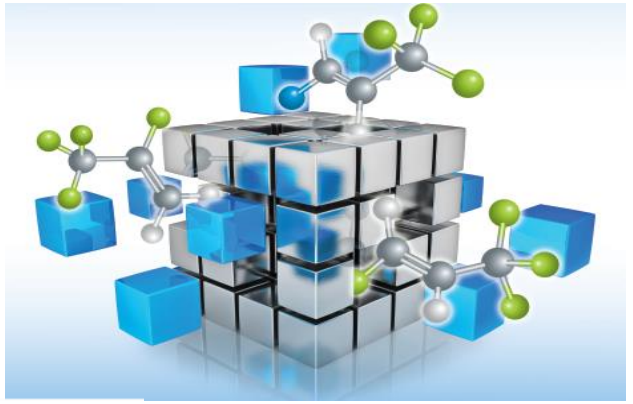

October 2018
Pawel Wisnik

ECO-EFFICIENCY COMPARISON OF SUPERMARKET ARCHITECTURES

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AGENDA

- Introduction to commercial refrigeration
- Environmental metrics
- Introduction to Eco-Efficiency
- Stores layouts
- Architecture analysis
- Results
- Conclusions

COMMERCIAL REFRIGERATION AND CARBON FOOTPRINT

- Commercial refrigeration
  - Is a major user of high global-warming-potential (GWP) fluids like R-404A, R-507A
  - Experiences high leak rates especially in large centralised systems
  - Thus contributing to increase of carbon footprint significantly
  - Is affected by bans and phase down of the f-gas regulations
  - Refrigeration accounts for more than 50% of energy consumption

METRICS FOR CARBON FOOTPRINT

- Global Warming Potential:
  - Used legislators for its simplicity, is a measure of the direct impact on the environment, depending on the system leak rate, it can only capture 10 to 35 % of the total environmental impact

- Total Equivalent Warming Impact:
  - Is the measure of direct and indirect impacts, with the indirect impact being the result of the energy usage to drive the refrigeration system, unlike GWP, TEWI can capture up to 95% of the environmental impact

- Life Cycle Climate Performance:
  - Residual 5% not covered by TEWI, can be done by comprehensive LCCP

Drawback of all above metrics is their one-dimensional nature

They do not show financial impact while installing or operating a system, or reducing environmental impact of your system by installing auxiliary hardware

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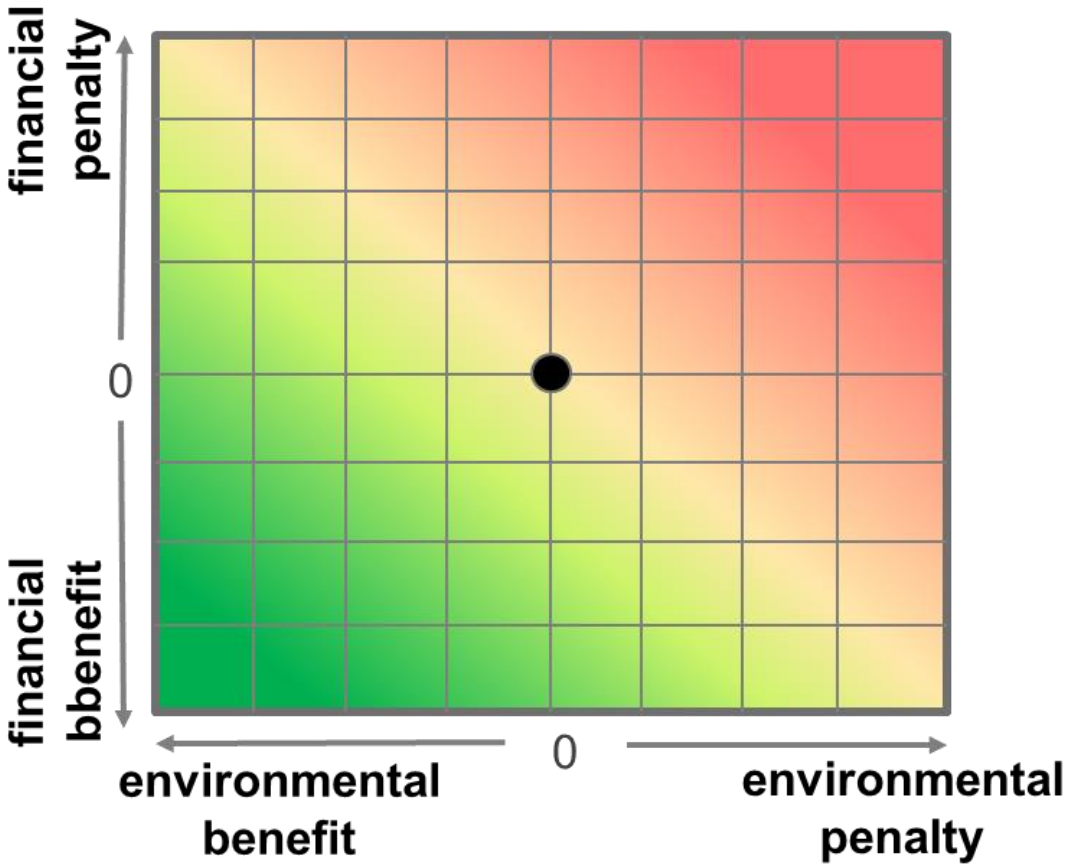
TWO-DIMENSIONAL METRIC

- ECO-EFFICIENCY:
  - Covers both environmental impact (TEWI) and financial impact (CAPEX and OPEX)

	Metric type	% of capture of impact		
		Environmental	Financial	
GWP	1 dimension	up to 35%	0%	☹
TEWI	1 dimension	up to 95%	0%	😐
LCCP	1 dimension	up to 100%	0%	😐
Eco-Efficiency	2 dimensions	up to 95%	up to 100%	☺



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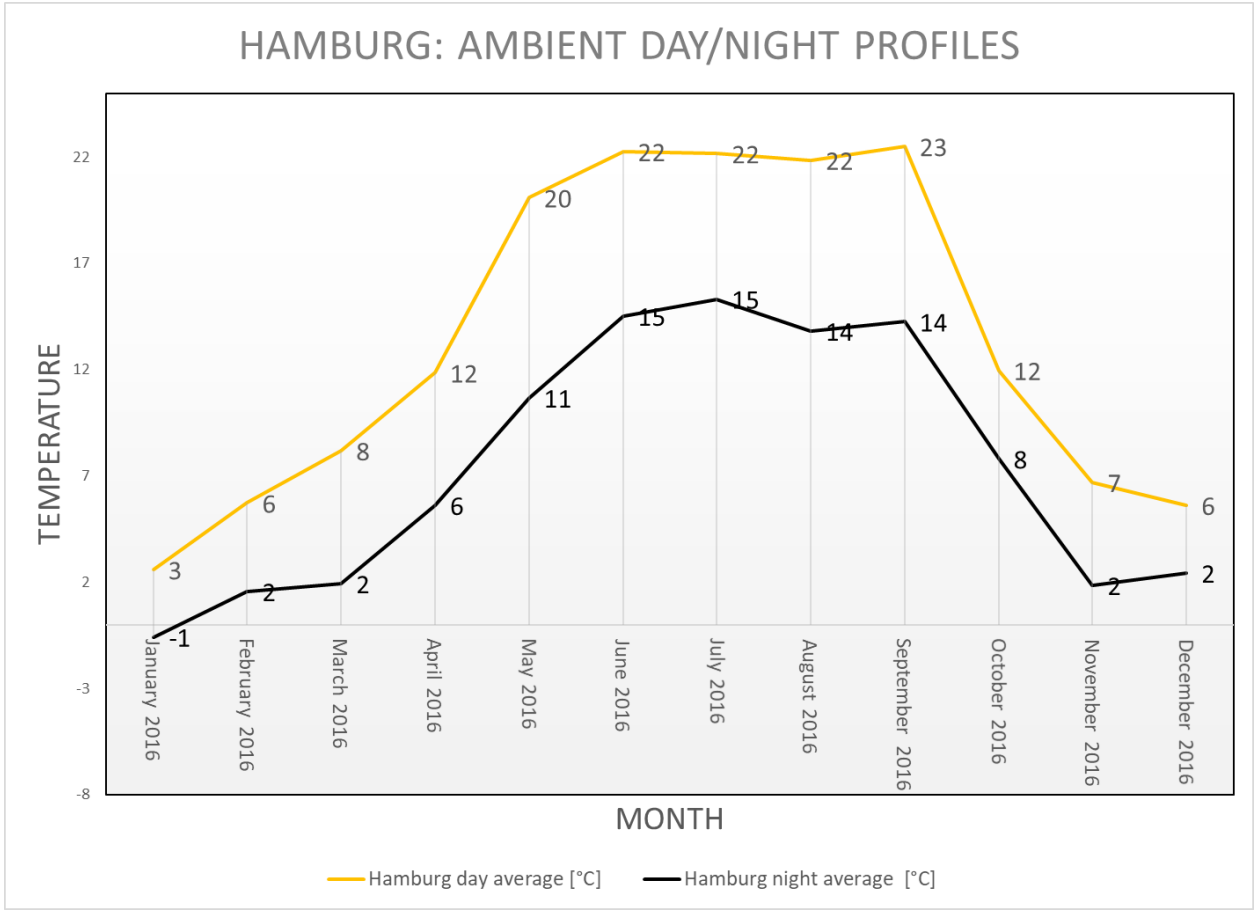
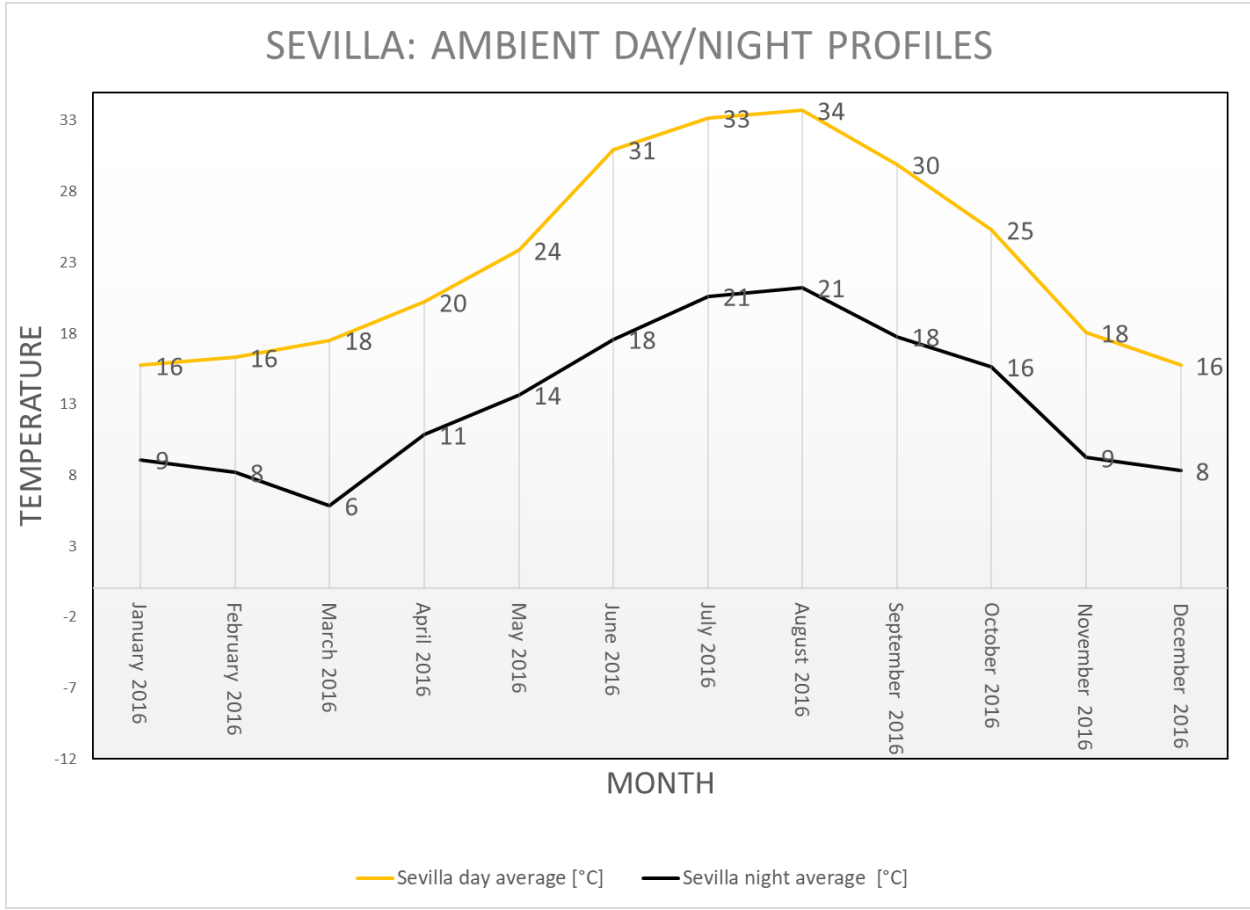
ECO-EFFICIENCY MODEL-DETAILS

WHAT IS MODELLED IN ECO-EFFCIENCY?

- Stores with sales area 500 m^2 and 2 000 m^2
- Located in Hamburg (D) and Seville (ES)





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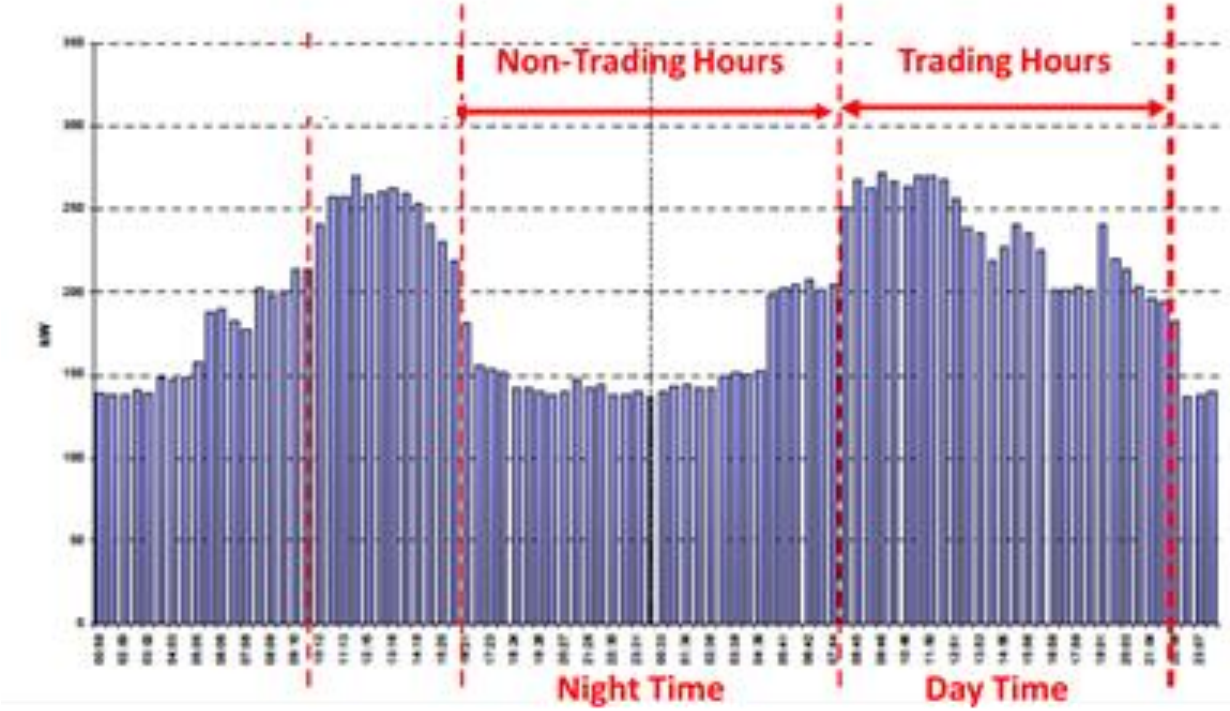
ECO-EFFICIENCY MODEL-DETAILS

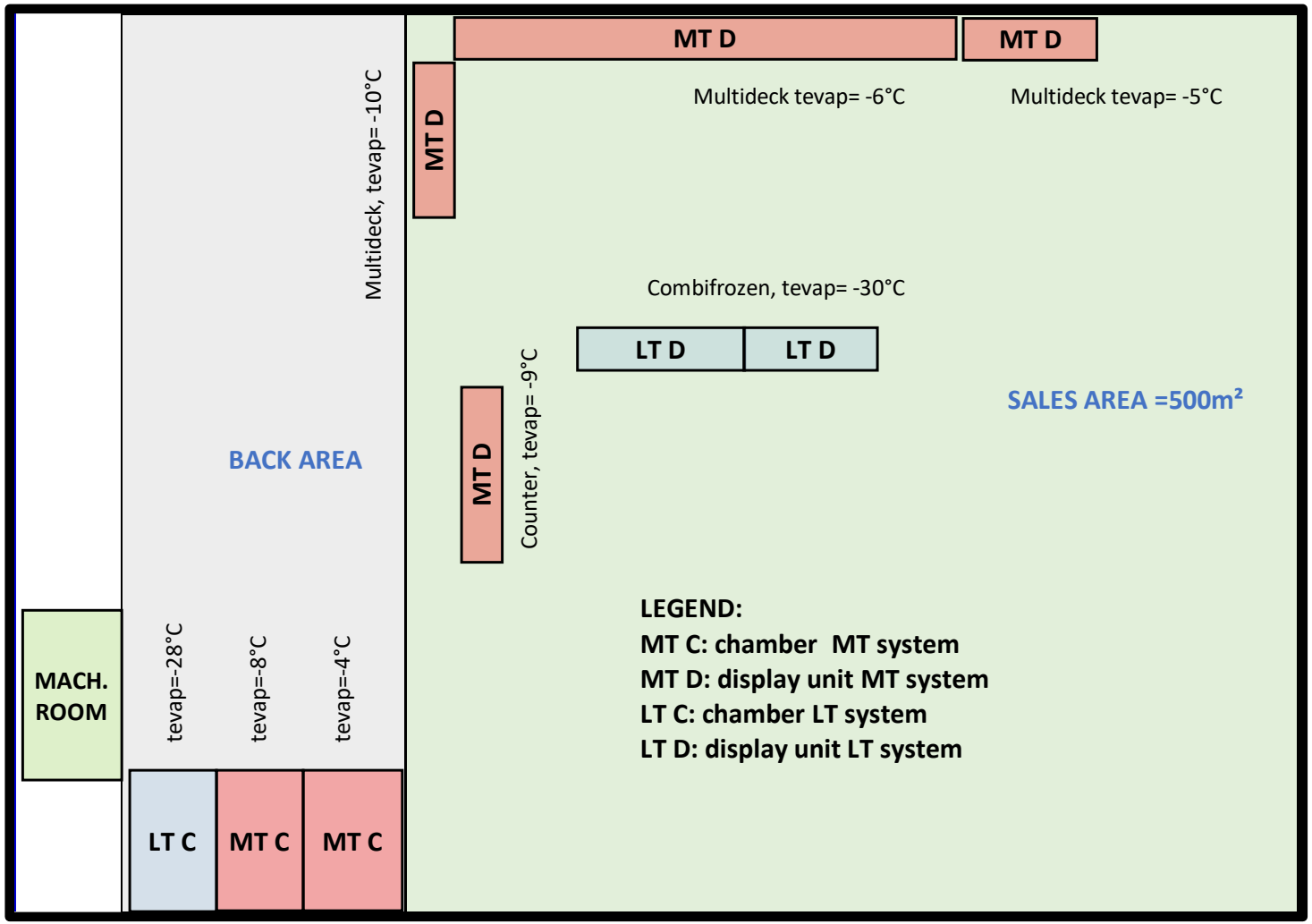
WHAT IS MODELLED IN ECO-EFFCIENCY?

- Refrigeration load in medium-temperature system is 22 and 78 kW respectively, in low-temperature system is 4,5 and 18 kW respectively
- Trading hours are 8 am – 8 pm, non-trading hours 8 pm – 8 am
- During trading hours refrigeration load is 100%, during non-trading it is 50%



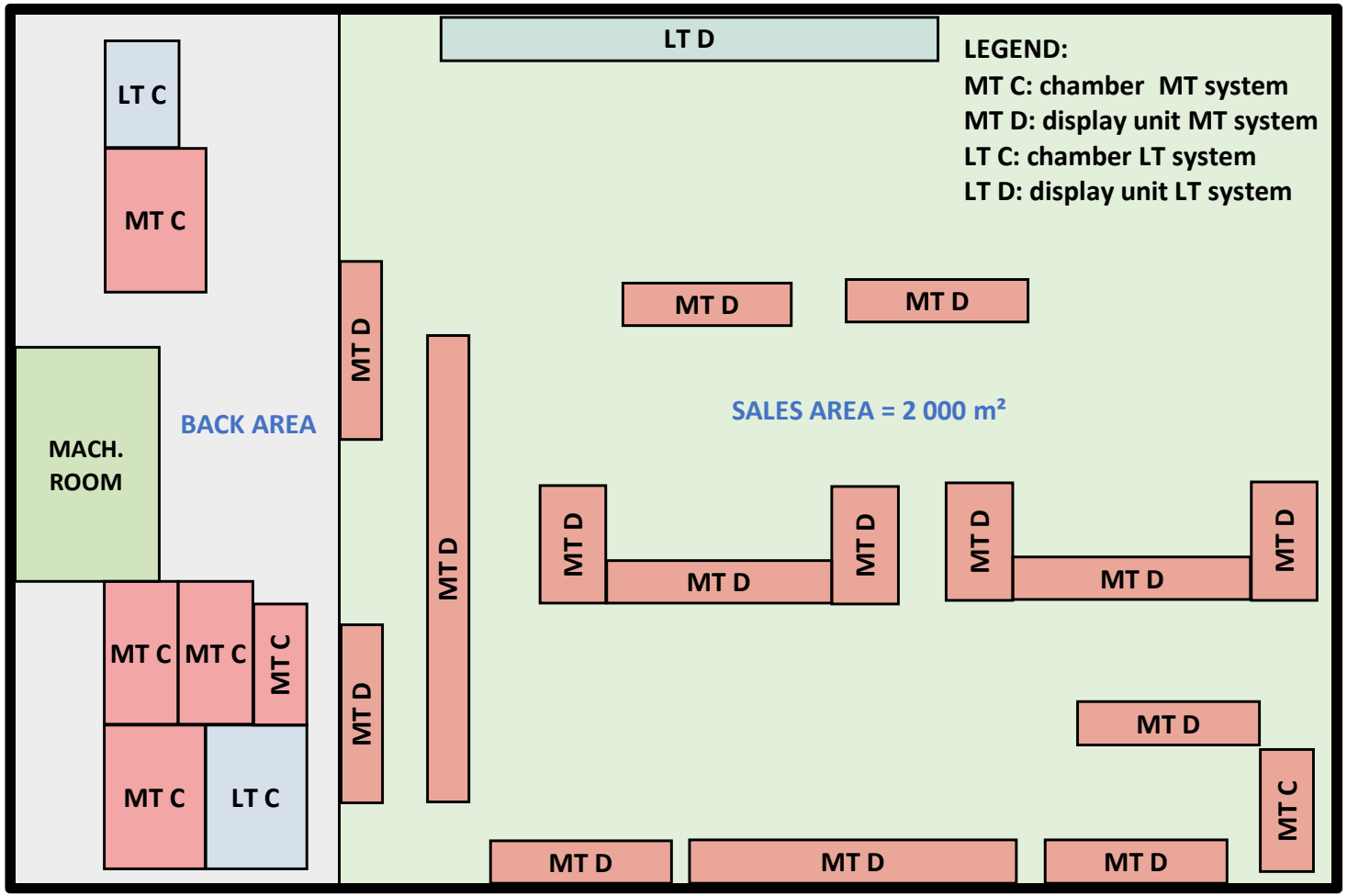
ECO-EFFICIENCY MODEL-DETAILS

- TYPICAL LAYOUT OF SUPERMARKET WITH 500 m^2 SALES AREA



ECO-EFFICIENCY MODEL-DETAILS

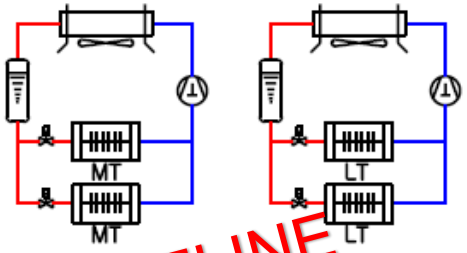
- TYPICAL LAYOUT OF SUPERMARKET WITH 2 000 m^2 SALES AREA



ECO-EFFICIENCY MODEL-DETAILS

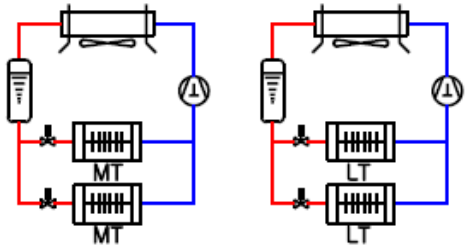
WHAT ARCHITECTURES ARE MODELLED?

ARCH 1. DX R-404A FOR MT AND LT

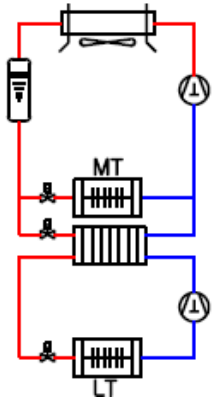


BASELINE

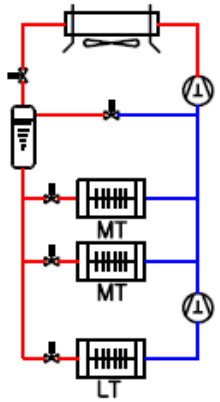
ARCH 2. DX R-448A FOR MT AND LT



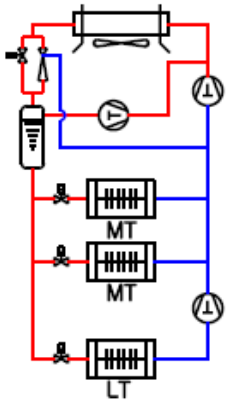
ARCH 3&7. CASCADE R-1234ze OR R-1233zd AND CO2



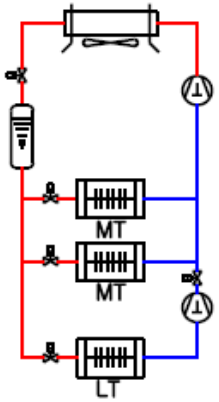
ARCH 4a. BOOSTER CO2



ARCH 4b. BOOSTER CO2 WITH PARALLEL COMP. AND EJECTOR



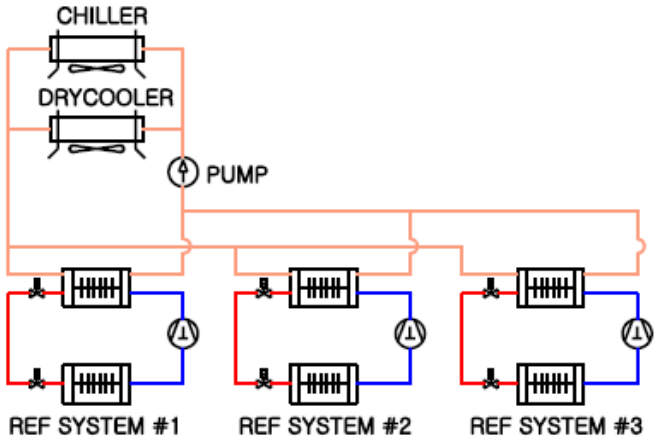
ARCH 5. BOOSTER R-448A



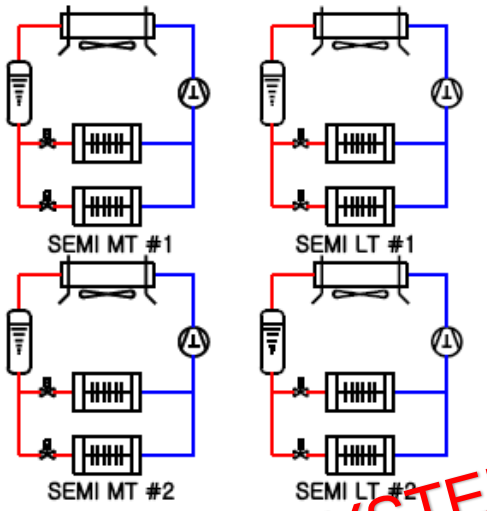
ECO-EFFICIENCY MODEL-DETAILS

- WHAT ARCHITECTURES ARE MODELLED?

ARCH 6. WATERLOOP R-455A/R-1234ze/GLYCOL



ARCH 8. SEMI DX R-448A FOR MT AND LT



MULTIPLE SYSTEMS

ECO-EFFICIENCY MODEL-DETAILS

- MODEL DETAILS:
  - System life span 15 years
  - Leak scenarios:
  - 15% and 5% for centralized systems,
  - 5% and 1% for semi-distributed systems
  - 1% for water-loop systems and chiller
  - Centralized systems: t_{evap} @ rack -10^{o}C , water loop and semi-distributed systems:
  - t_{evap} @ comp variable, useful SH 10K, SC 5K

  - Centralized systems: t_{evap} @ rack -35^{o}C , water loop and semi-distributed systems:
  - t_{evap} @ comp variable, useful SH 10K, SC 5K

  - For glided refrigerants series R-4xx, t_{evap} and t_{cond} are taken as mean

  - Rated temperature difference in condenser/gas-cooler is 10K, in evaporators 8K

  - Minimum allowable t_{cond} 20^{o}C

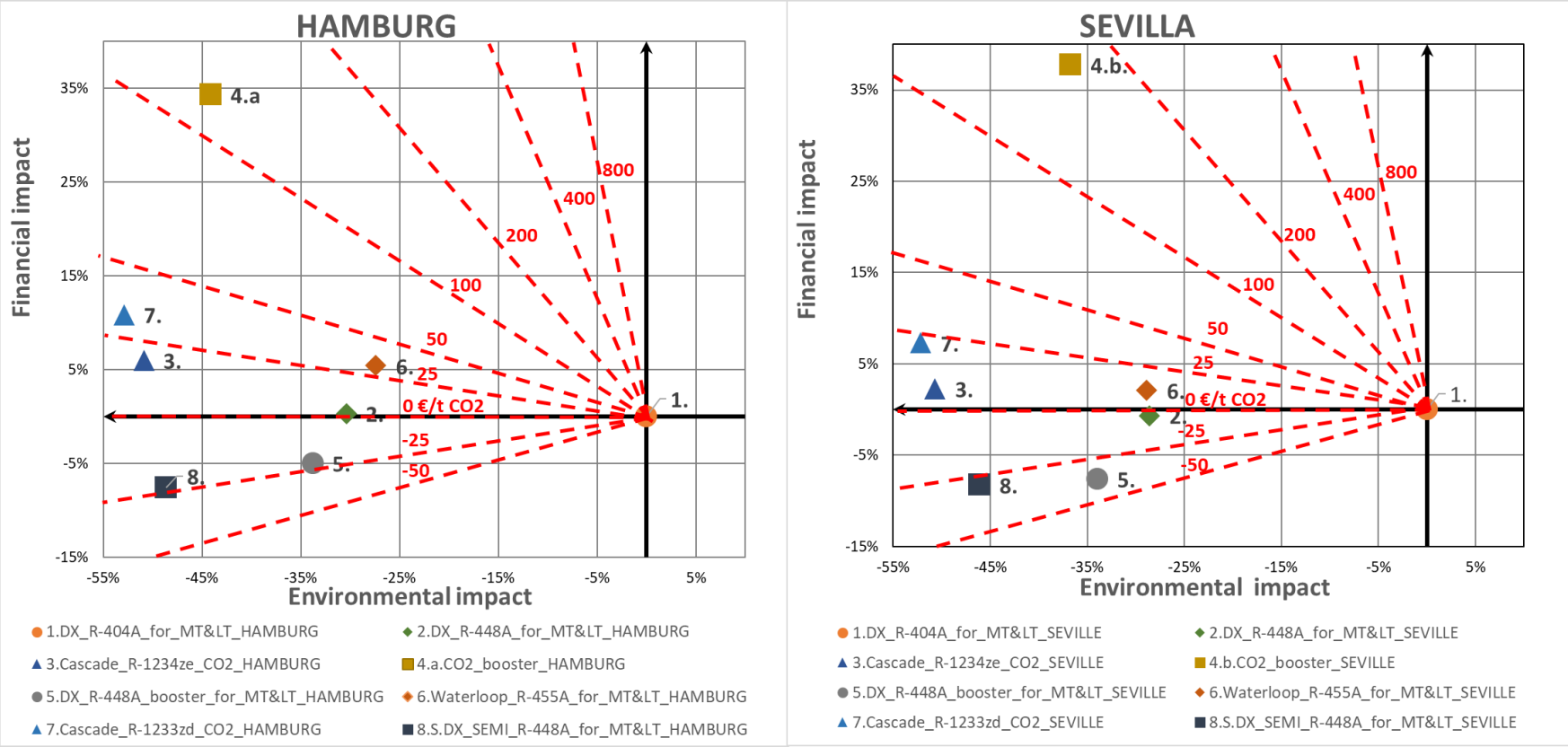
ECO-EFFICIENCY MODEL-DETAILS

- MODEL DETAILS:

  - CAPEX
  - Comprehensive BOM developed for each architecture, cost of assembling and commissioning
  - Quotation from various equipment manufacturers
  - Market intelligence and 3rd party validation

  - OPEX
  - Electricity cost 0.094€/kwh
  - Electricity powers of components sourced form publicly available selection software’s
  - Electricity consumption modelled using those software's
  - Maintenance, twice a year (basic maintenance, filter and oil change, minor repairs)
  - Refrigerant top up

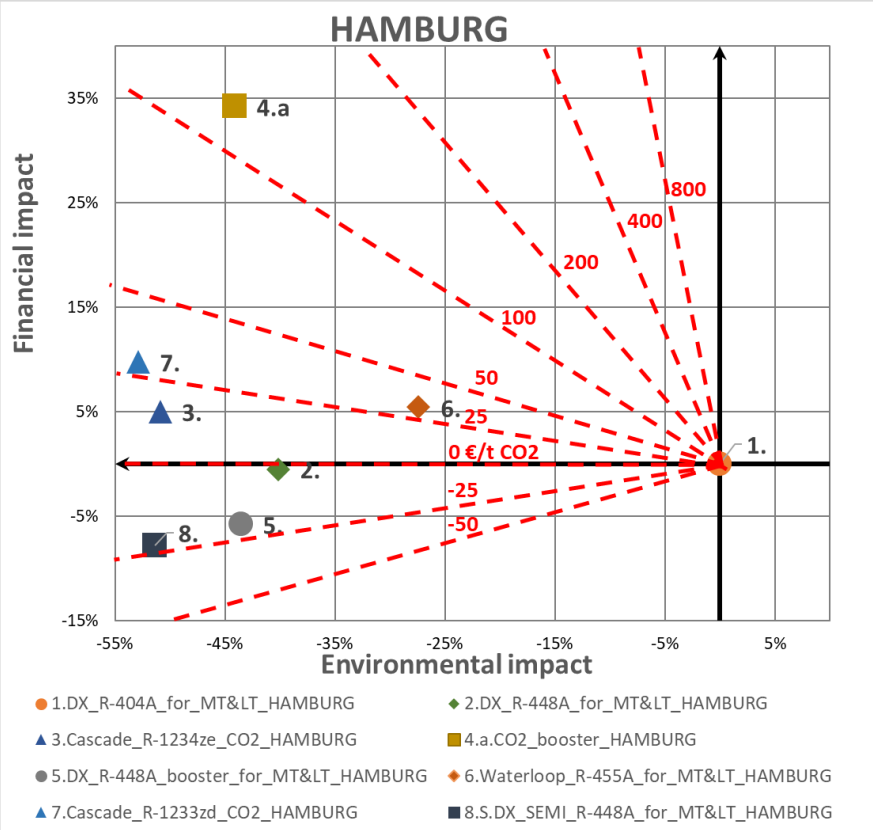
RESULTS: 500 M²

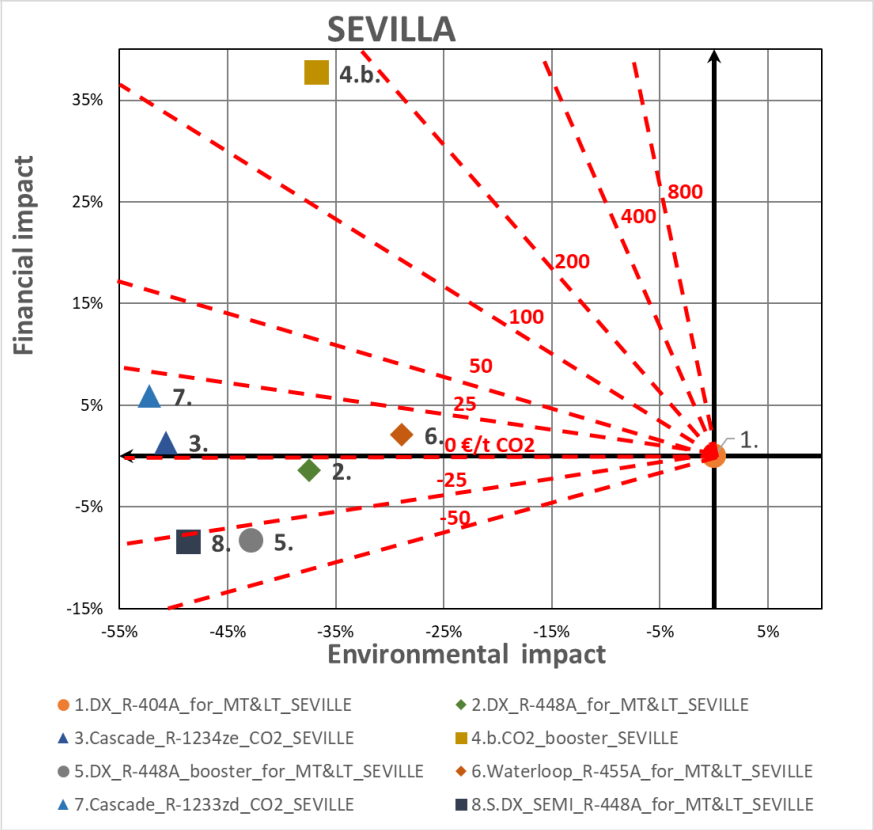


Leak rates:
15% centralised
5% semi dist.
1% water loop

- Water-loop system (6.) offers reduction in environmental impact similar to typical HFC/HFO blend centralized system (2.) with slightly higher financial impact
- Outstanding performances of semi distributed system based on HFC/HFO blend (8.)
- HFO/CO2 cascades based on R-1233zd and R-1234ze (3.&7.) outperforms all other architectures in terms of environmental impact
- TCO2 (4.A.&4.B.) not viable option due to huge financial impact

RESULTS: 500 M²





Leak rates:
5% centralised
1% semi dist.
1% water loop

- Environmental impact of typical centralized system based on HFO/HFC blend (2.) equal to TCO2 booster (4.a.&4.b.) with significantly reduction on financial impact
- Environmental impact of HFO/HFC blend booster (5.) equal to TCO2 booster (4.a.&4.b.), since financial impact of arch (5.) far better than (4.a. &4.b.)
- Semi-distributed system based on HFC/HFO blend (8.) are the best option for this store size format from financial and environmental impacts point of view

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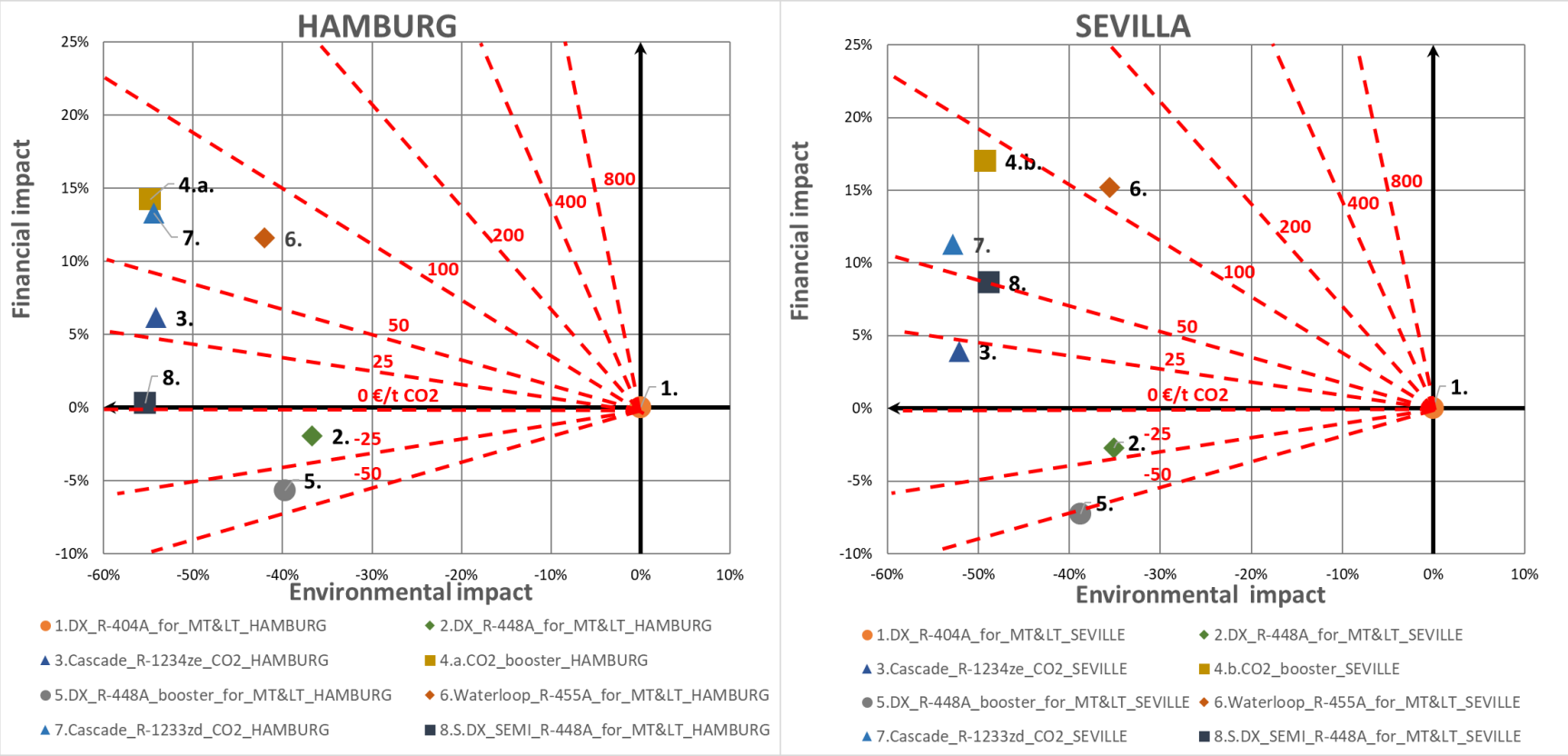
RESULTS: 2 000 M²



Leak rates:
15% centralised
5% semi dist.
1% water loop

- The most favorable financial impact offered by typical HFC/HFO blend centralized system (2.) and HFC/HFO blend booster centralized (5.)
- Financial impact of water loop (6.) and HFO/CO2 cascades based on R-1233zd (7.) impacted by excessive OPEX
- HFO/CO2 cascades based on R-1234ze (3.) and semi distributed system based on HFC/HFO blend (8.) are the best option for this store size at colder ambient

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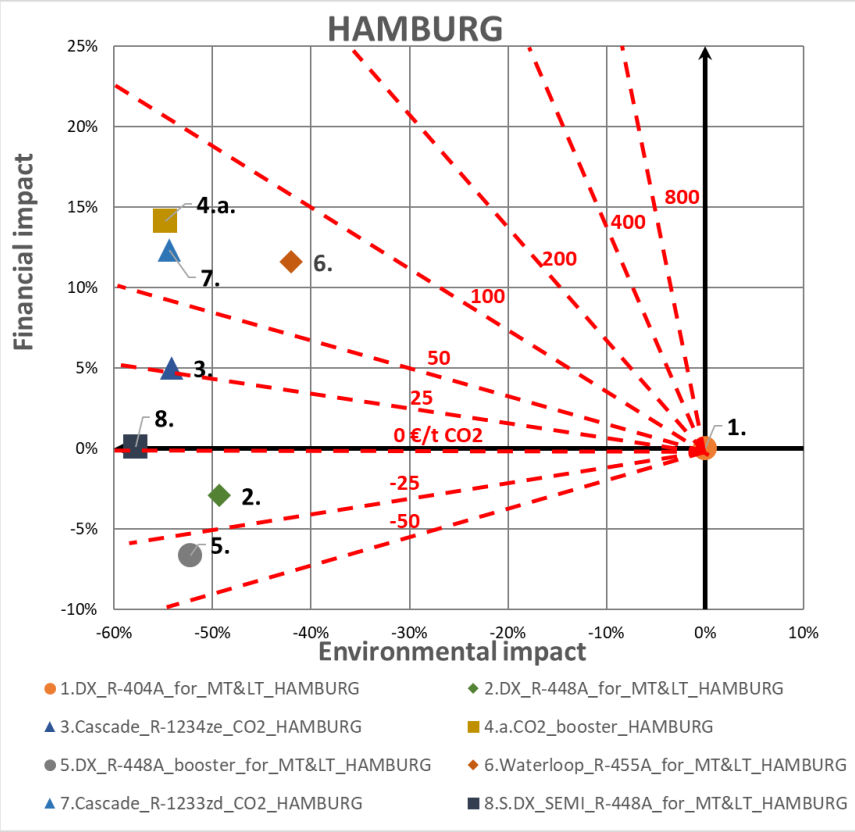
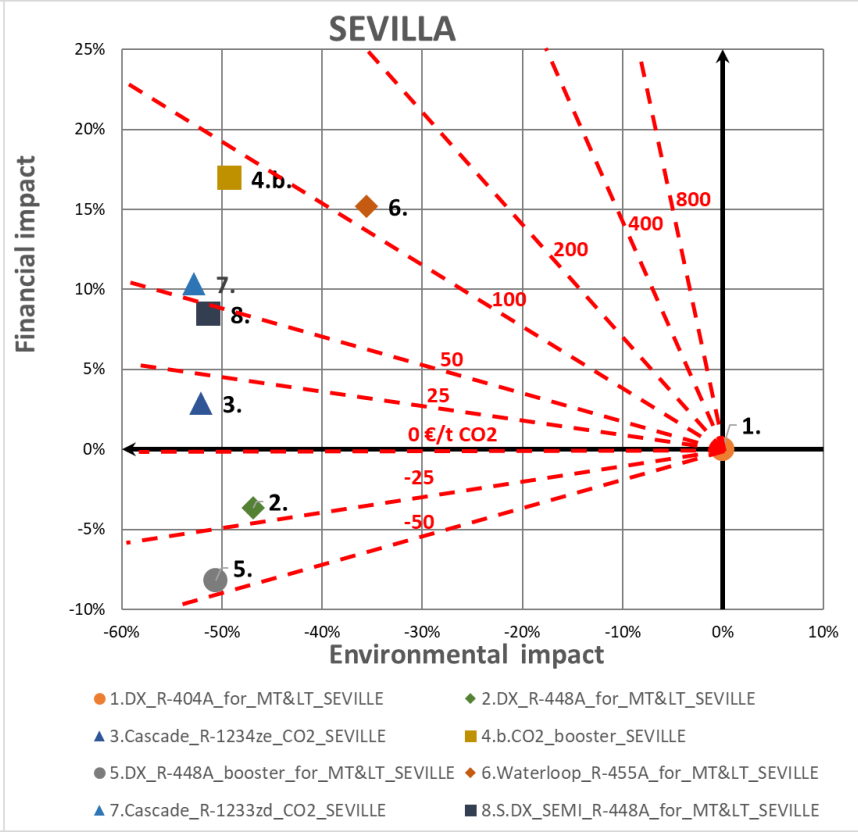
RESULTS: 2 000 M²





Leak rates:
5% centralised
1% semi dist.
1% water loop

- Centralized system based on HFO/HFC blend (2.) , HFO/CO2 cascades based on R-1234ze (3.) , HFO/HFC blend booster (5.) and semi distributed system based on HFC/HFO blend (8.) are the best option for this store size at colder ambient, for high ambient architectures 2., 3. and 5. are the best ones

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CONCLUSIONS

- Eco-efficiency is a powerful tool to compare commercial refrigeration architectures
- Standard DX systems can equally have a considerable reduction in environmental impact but with financial benefits
- Small investments to reduce leak rates of HFC/HFO systems would considerably reduce the environmental impact of these systems, making them a much better solution for both the environment and the economics
- Architectures developed based on cascade systems with HFO/CO2 offers very good environmental impact, thus seem to be viable option for store size ranges covered here
- Although R-744 systems have good environmental impact this is mainly achieved because of the ultra-low GWP of the refrigerant, and at a considerable financial impact