Benchmarking energy consumption, IEA HPP Annex 44

Performance indicators for energy efficient supermarket buildings

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DANISH TECHNOLOGICAL INSTITUTE

EUDP
Energiteknologisk udvikling og demonstration

OBJECTIVES

Objectives
- create performance indicators for energy efficient supermarket buildings, so that measurements and monitored data can be converted into knowledge concerning the energy performance.
- create knowledge concerning the energy efficiency of supermarket buildings for decision making, benchmarking and development of energy efficiency strategies.

Is "your" supermarket building energy efficient?

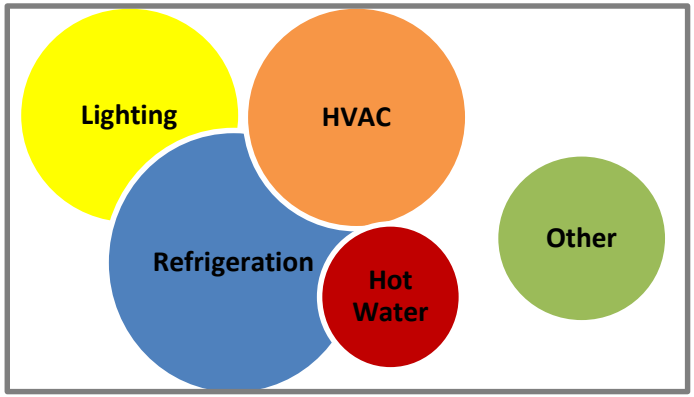
- *Compared to other supermarkets in same chain*
- *Compared to other supermarkets in the same country*
- *Compared internationally*.

SCOPE

- Supermarkets (ISIC 4711)

  non-specialized stores, with food, beverages or tobacco predominating

- All energy systems (thermal & electric)

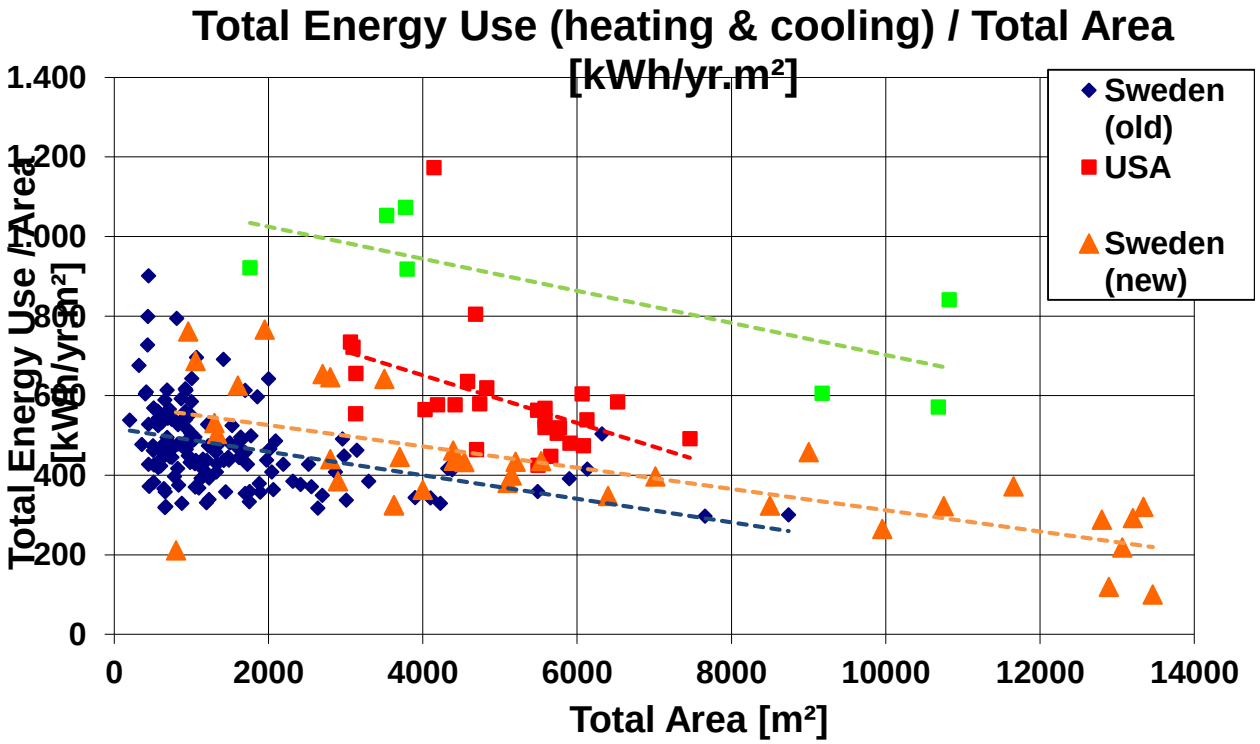


Energy systems	% energy use
Lighting	27 %
HVAC	13 %
Refrigeration	47 %
Hot water	3 %
Others	10 %

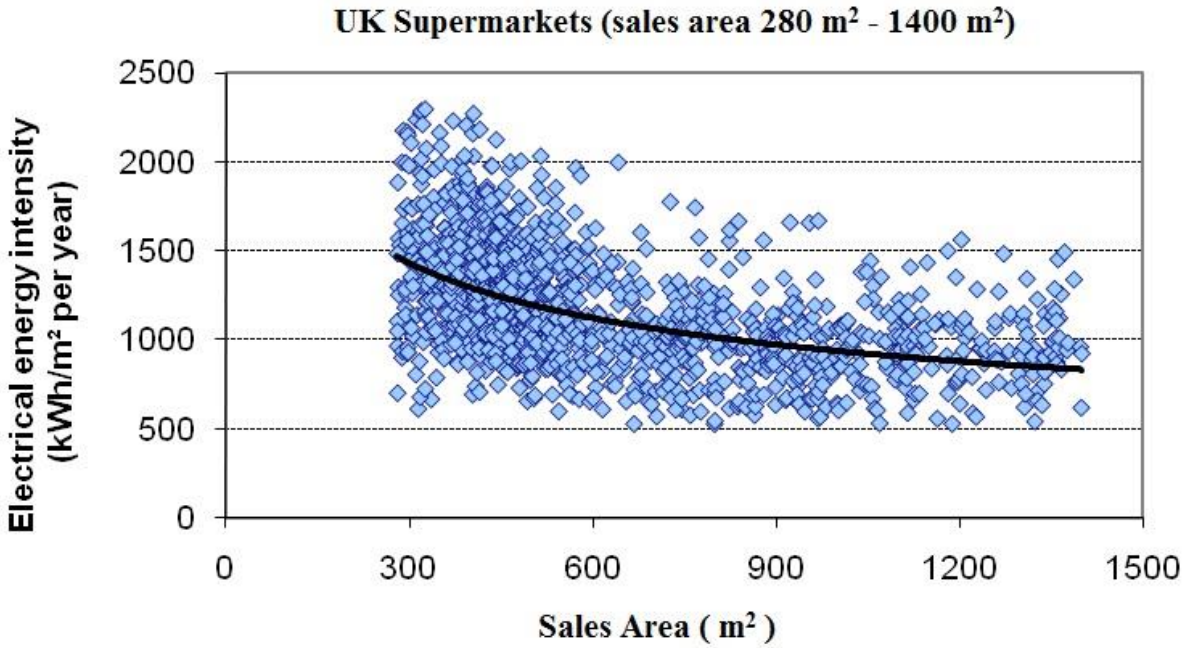
Supermarket refrigeration systems are more and more used as heat pumps (heat recovery)

RELATED (EARLIER) WORK.

(IEA-HPT Annex 31)



RELATED (EARLIER) WORK. *(Tassou et al. - UK)*



ISSUES ARISING FROM (EARLIER) WORK.

Comparison basis:

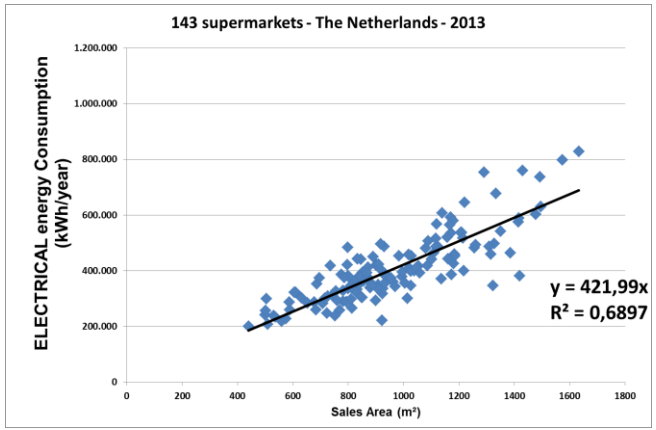
- Supermarket Size:
  - * First source (Annex 31) uses TOTAL Supermarket Area
  - * Second source (Tassou) uses Supermarket SALES Area
- Energy consumption:
  - * First source (Annex 31) uses TOTAL energy consumption/ m^2.year
  - * Second source (Tassou) uses ELECTRICAL energy consumption/ m^2.year
- What is the preferential choice?
- How do data from these sources relate?

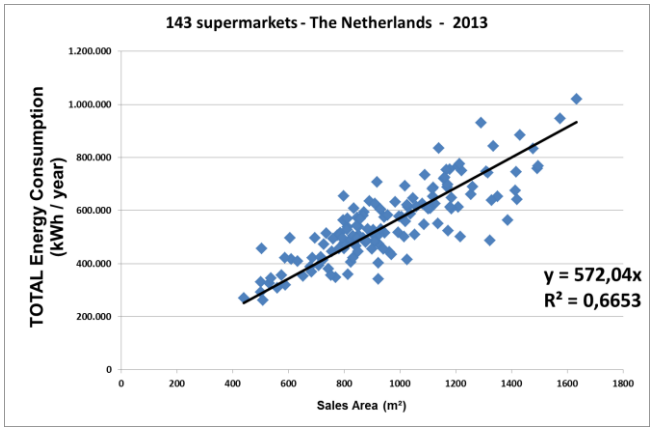
ADDITIONAL DATA COLLECTION ANNEX 44

- In The Netherlands, energy performance data (energy use, indicators & energy saving options) has been collected for 150 supermarkets of one chain.
  - Data split in Electrical and Gas (for heating) consumption
  - 71 parameters describing each supermarket
  - Parameters include SALES area and TOTAL area
- Separate data sets are available for 2013 and 2014

ANALYSIS OF DUTCH DATA.

- ELECTRICAL consumption relates slightly better with supermarket size than TOTAL energy consumption. However, due to use of heat recovery, TOTAL energy consumption must be considered.

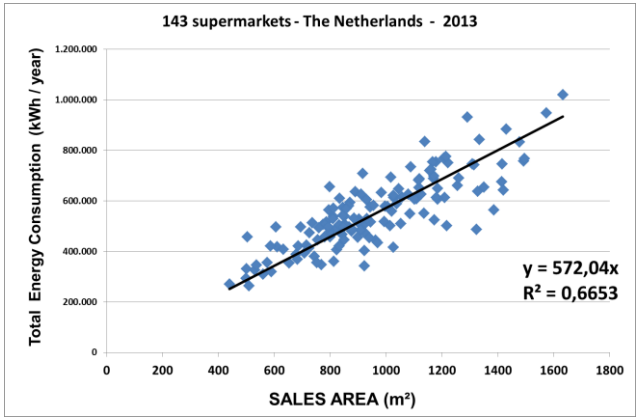


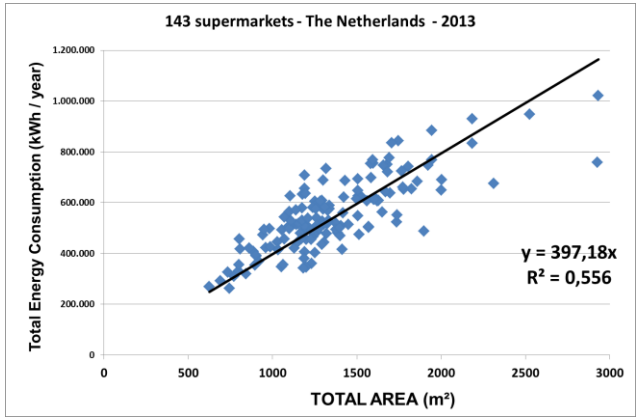


(Average TOTAL / ELECTRICAL energy consumption = 1,4)

ANALYSIS OF DUTCH DATA.

- SALES area relates better to energy consumption than TOTAL area, therefore SALES Area must be considered.

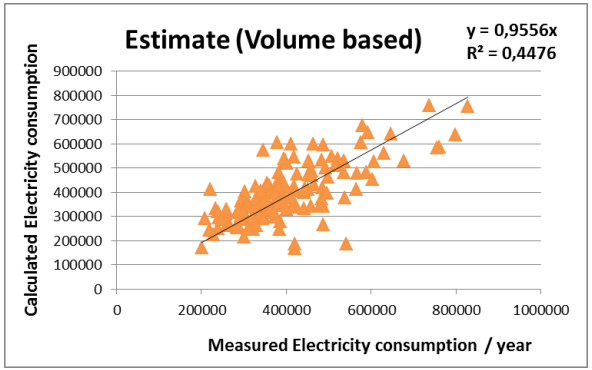


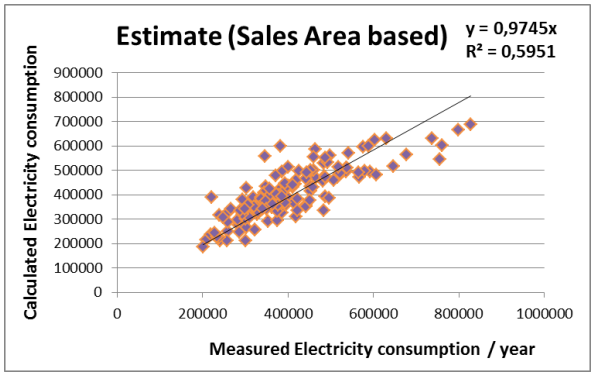


(Average TOTAL Area / SALES Area = 1,4)

ANALYSIS OF DUTCH DATA.

- Refrigeration is a large part of total energy consumption, therefore the amount of refrigerating equipment (fresh & frozen volumes in m^3) appeals as a possibly good indicator for total energy consumption.



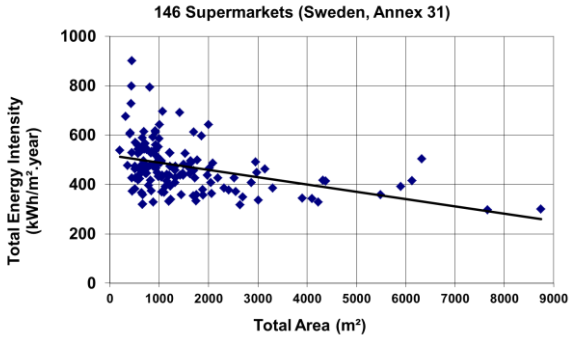


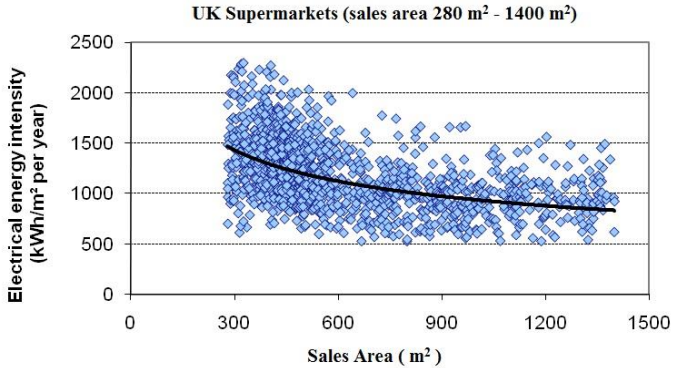
Estimate (Volume based) = 4300 V1 + 14039 V2 + 804 V3 + 594 V4 (kWh/year)

V1 = Volume RDC's, fresh (m^3)
V2 = Volume RDC's, frozen (m^3)
V3 = Volume Storage, fresh (m^3)
V4 = Volume Strage, frozen (m^3)

LOOKING BACK AT RELATED (EARLIER) WORK:

- NL: Average TOTAL / ELECTRICAL energy consumption = 1,4
- NL: Average TOTAL / SALES area = 1,4
- Graphs (NL): Total energy vs Total area ≈ Electrical energy / Sales area





- Rough comparison of graphs suggests supermarket energy consumption in UK higher than in Sweden
- Total energy consumption / Total area: 452 kWh/m².year (Annex 31 data Sweden 2006-2011; 290 – 9000 m²)
- Total energy consumption / Total area: 413 kWh/m².year (Annex 44 data Netherlands 2013; 600 – 2900 m²)

ENERGY SAVING OPTIONS

NL data contains info on 65 energy saving options (implemented yes/no). Statistically relevant options (t-test, 5%) are listed in the table below.

option	2013 data Savings %	2014 data Savings %
Night Covers on RDC's		6,4 %
10744K (Glass doors on Multidecks)	9,4 %	
IMa		6,8 %
Weather control on heating		6,4 %
RDC Settings (3 savings options)	-/- 5,7 %	
Lighting control (3 savings options)		6,5 %
Ventilation control		6,9 %
Insulation of heating pipework		5,7 %

Heat Recovery is statistically relevant for gas consumption, not for total energy consumption. Savings on overall consumption are 5,3 % (2013 data) and 9,0 % (2014 data)

TOTAL ENERGY INTENSITY (EI) ESTIMATIONS.

- **Most simple form:**

2013 data: $EI_{(estimate)}$ = 572,04 [kWh/yr.m²]

Average deviation 11,7 %

2014 data: $EI_{(estimate)}$ = 528,85 [kWh/yr.m²]

Average deviation 13,4 %

$$EI_{(estimate)} = 550 \ [kWh/yr.m^2]$$

- With size dependency (One parameter, Sales Area (SA) in m²):

2013 data: $EI_{(estimate\ SA)}$ = 572,04 – (SA – 1078) * 0,111 [kWh/yr.m²]

Average deviation 11,4 %

2014 data: $EI_{(estimate\ SA)}$ = 528,85 – (SA – 1105) * 0,075 [kWh/yr.m²]

Average deviation 13,1 %

$$EI_{(estimate\ SA)} = 550 - (SA - 1100) * 0,09 \ [kWh/yr.m^2]$$

EI ESTIMATIONS WITH ENERGY SAVING OPTIONS.

- Based on individual statistically relevant parameters:

$EI_{(estimate\ N.)} = EI_{(estimate\ SA)} * \prod (1 + (presence - average\ presence) * savings\ \%)$

- Savings % determined per individual savings option.
- Average deviation decreases at 1st option, then increases
- Cause: savings % determined this way are not independent

- Based on multi variable linear regression:

$EI_{(estimate\ N.)} = EI_{(estimate\ SA)} * (1 - \sum (presence * Coefficient))$

- Coefficients determined from multi variable linear regression
- Average deviation decreases from 13,1 % to 12,4 %
- Coefficients are physically meaningless, relate to specific dataset.

Based on 2014 data from The Netherlands

PROPOSED FORMULA FOR ENERGY INTENSITY ESTIMATION AS A FUNCTION OF "N" PERFORMANCE INDICATORS

- Arbitrary number "N" of performance indicators:

$$EI_{(estimate\ N.)} = EI_{(estimate\ SA)} * \prod_{1...N} (1 + (presence - average\ presence) * savings\ \%)$$

- Estimate of Total Energy Intensity [kWh/m².year] with Sales Area basis
- Independent Performance Indicators only
- Average presence of P.I. needed (varies per dataset)
- Savings % determined from data, literature & physical interpretation

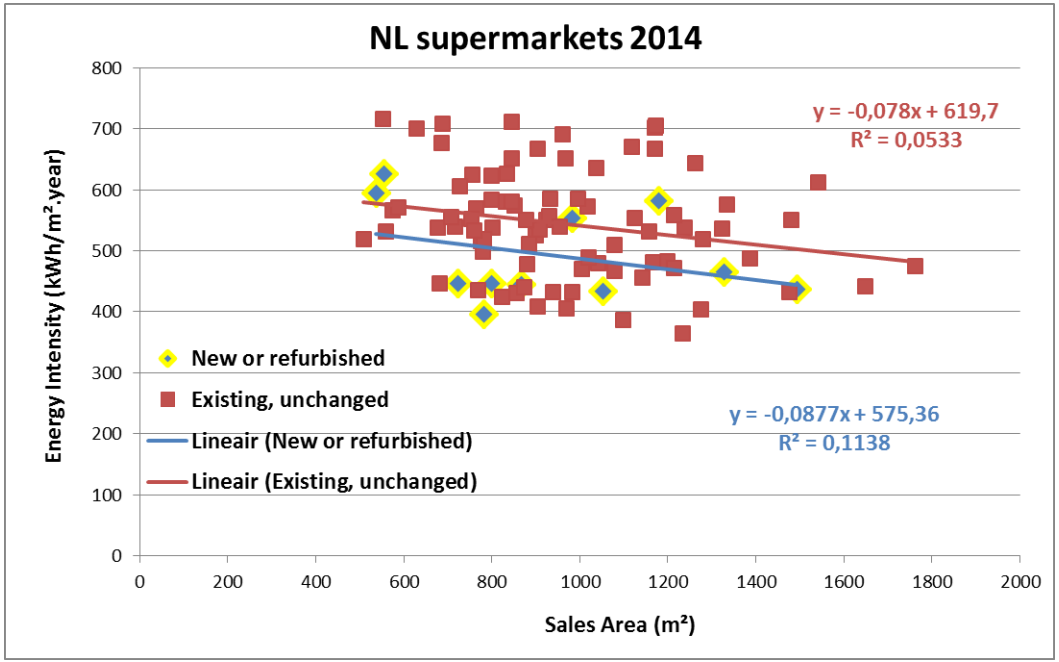
Based on 2014 data from The Netherlands

RESULTS SO FAR – OPTIONS FOR ONGOING WORK

The estimation of supermarket total yearly energy consumption based on Sales Area and (so far) available Performance Indicators still shows a large deviation from measured values (12,4 %). We conclude that we must include non – conventional indicators, to fully explain observed energy use and efficiency in practice.

Most notably, we are thinking of the maintenance and dynamics of the systems, sales volume or customer density, the indoor temperature & humidity, cleaning and loading procedures, and the training of personnel.

EXAMPLE: YEAR OF LAST REFURBISHMENT

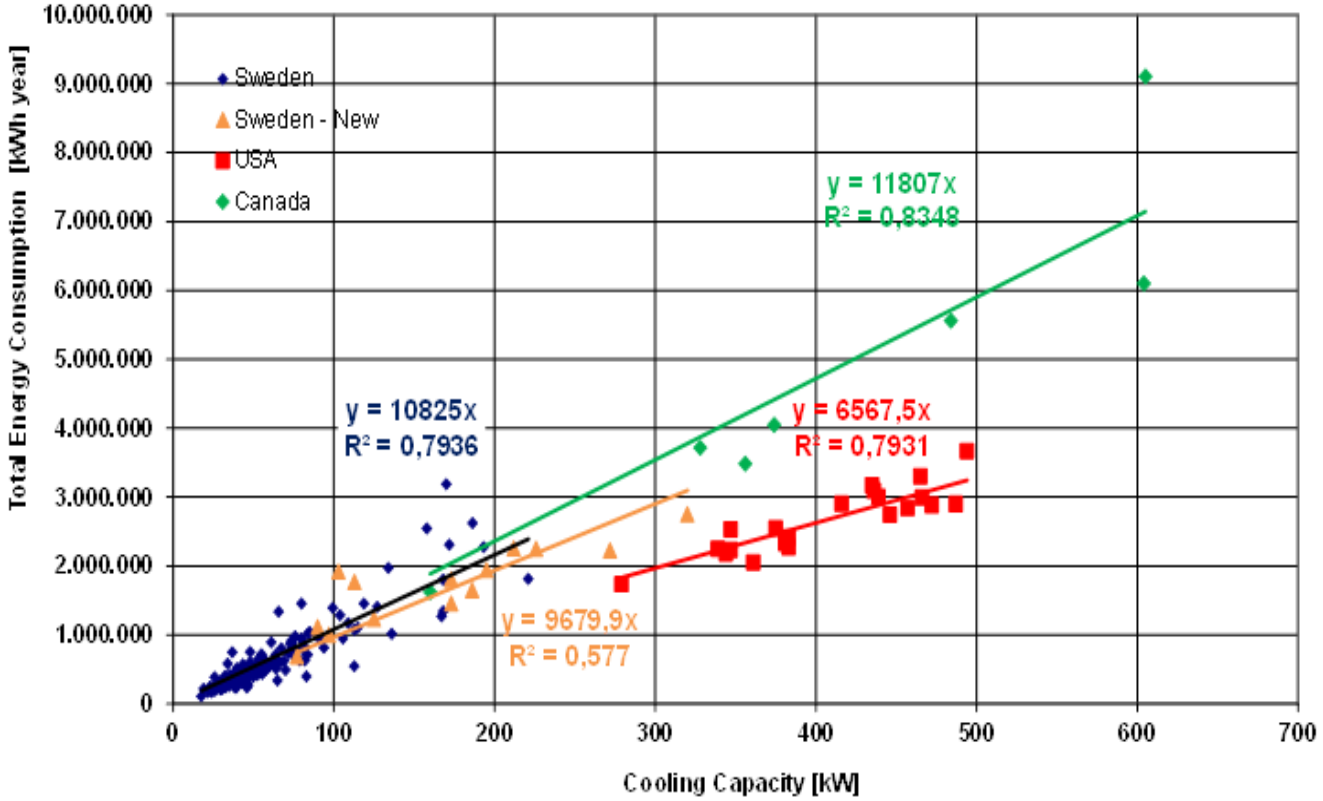


Statistically relevant (95%) decrease of Energy Intensity - 9,5 %

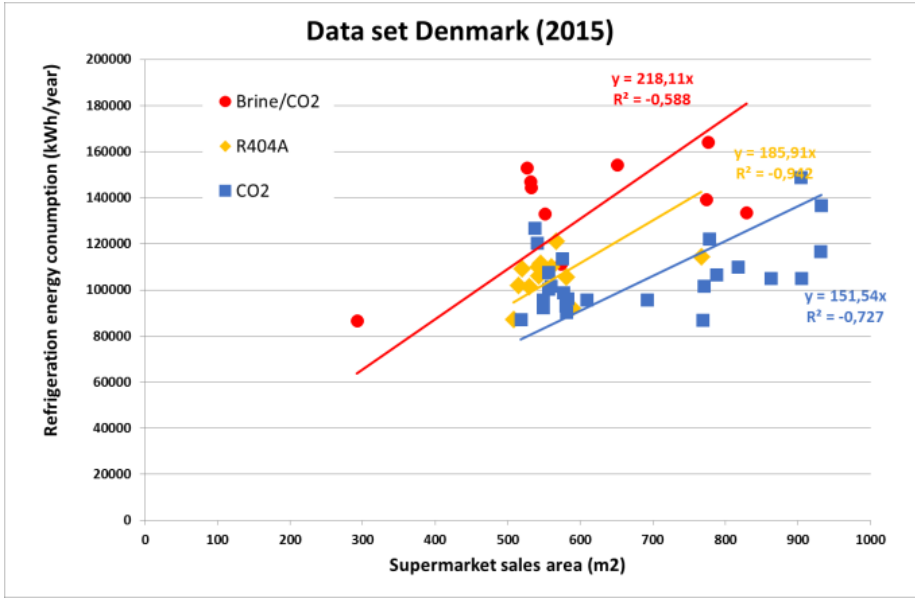
ONGOING WORK

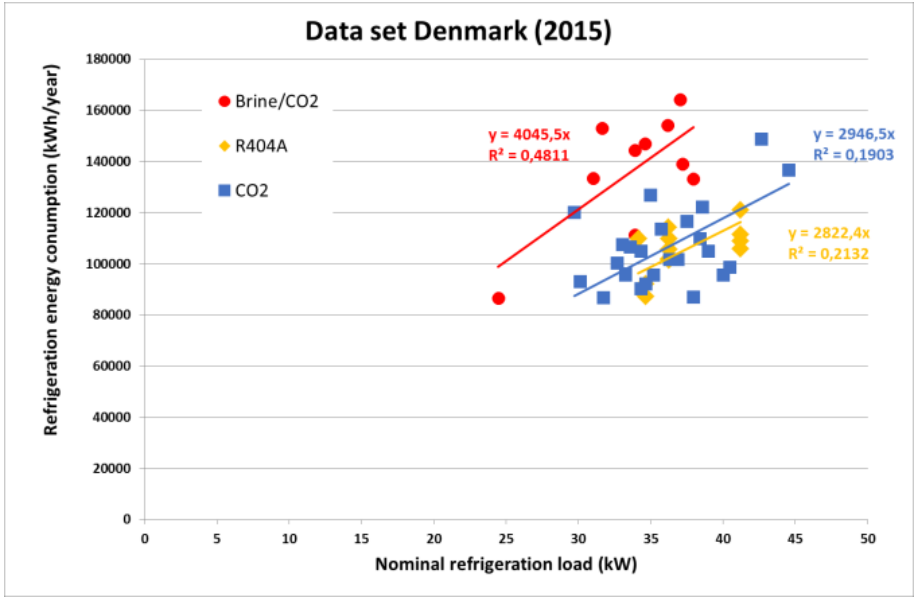
- Influence of control parameter settings – experimental work in Denmark.
- Influence of opening hours – (data from Annex 31 , Sweden)
- Influence of sales intensity
- Influence of outdoor climate (Sweden)
- Installed refrigeration capacity as performance indicator (Sweden)
- Automatically Estimated COP as performance indicator (Denmark)

Total consumption versus cooling capacity for selected foreign supermarkets



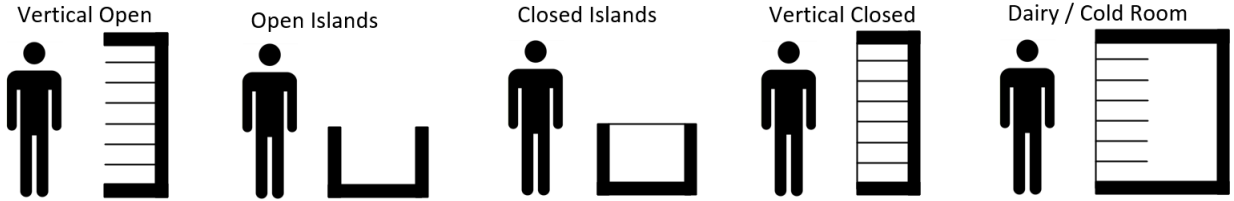
Electrical consumption for refrigeration systems in 47 Danish chain of supermarkets





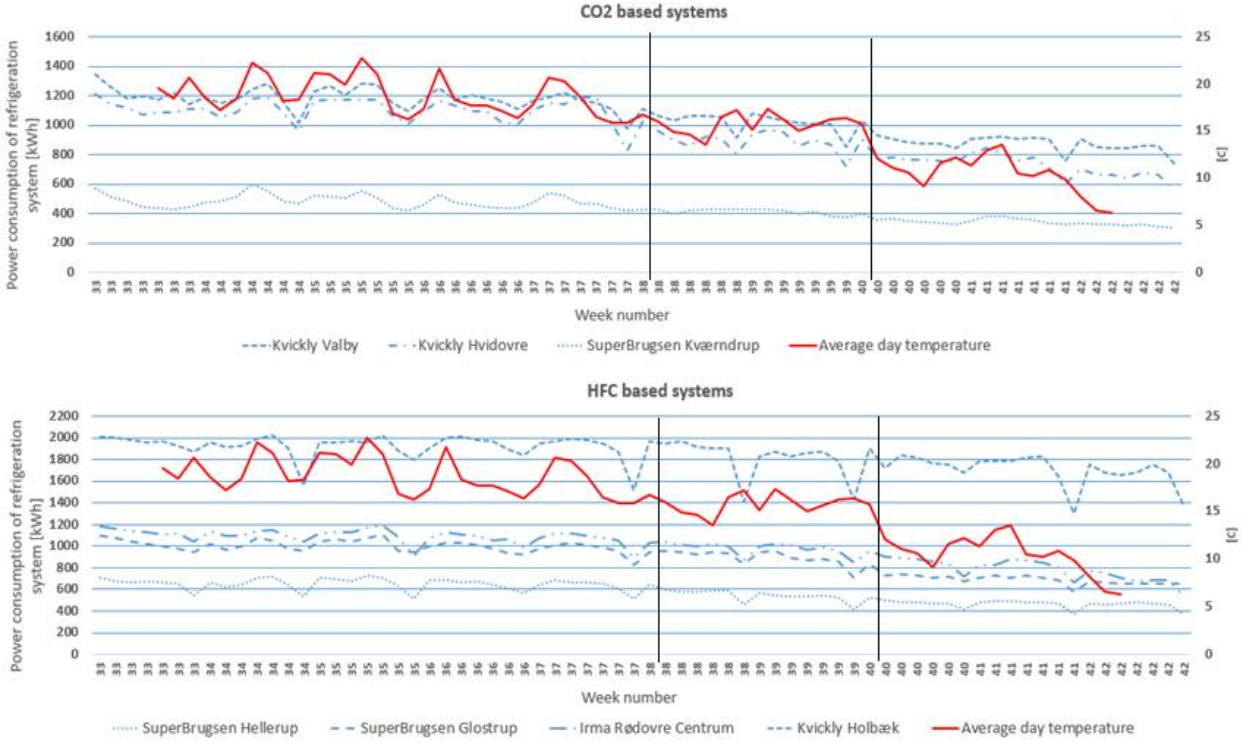
Yearly energy consumption as a function of sales area and nominal load

Calculation of nominal load



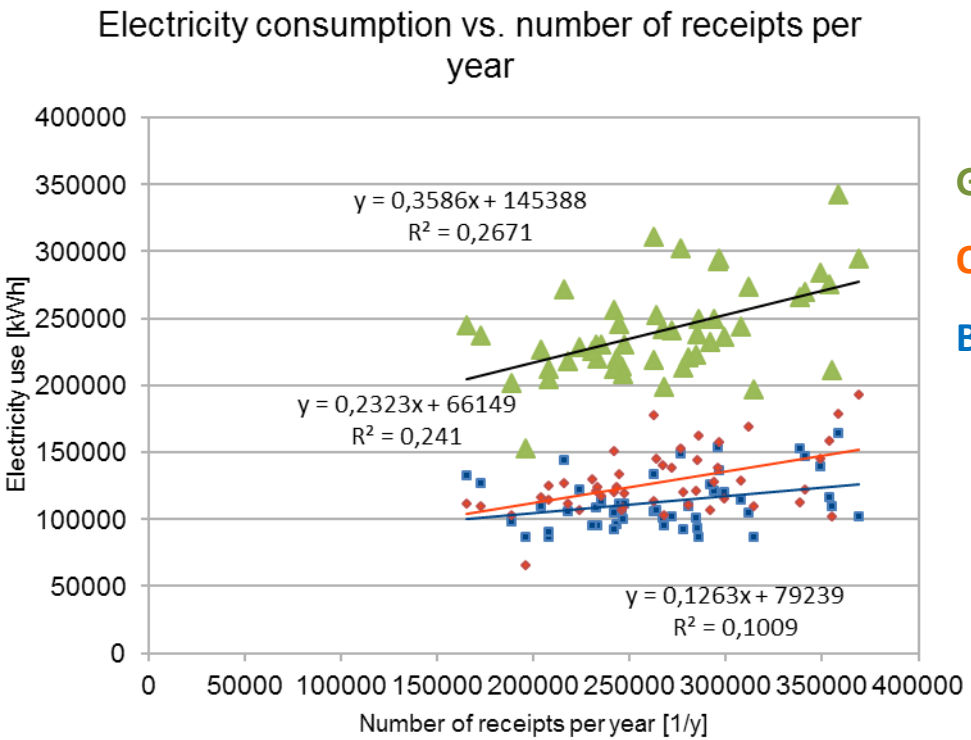
Type of display cabinet	Temperature	Evaporation temperature	Capacity
Vertical Open	0°C – 2°C	-10°C	1470 w/meter [length]
Vertical Open	2°C – 4°C	-10°C	1310 w/meter [length]
Vertical Closed	0°C – 2°C	-10°C	725 w/meter [length]
Vertical Closed	2°C – 4°C	-10°C	650 w/meter [length]
Closed Islands	-18°C	-31°C	420 w/meter [length]
Closed Islands	2°C – 4°C	-10°C	315 w/meter [length]
Open Islands	2°C – 4°C	-10°C	441 w/meter [length]
Closed End Islands	-18°C	-31°C	532 w/unit
Closed End Islands	2°C - 4°C	-10°C	400 w/unit
Diary/ Cold room	2°C – 4°C	-10°C	160 w/m^2
Glass doors for room	2°C – 4°C	-10°C	280 w/glass door
Frozen Storage	-18°C	-31°C	180 w/ m^2

Optimisation of set points saves 15-20% (2009)



4 plants with CO_2 optimized in 2016-2017 with same result

Sales volume, foot fall ~ receipts per year



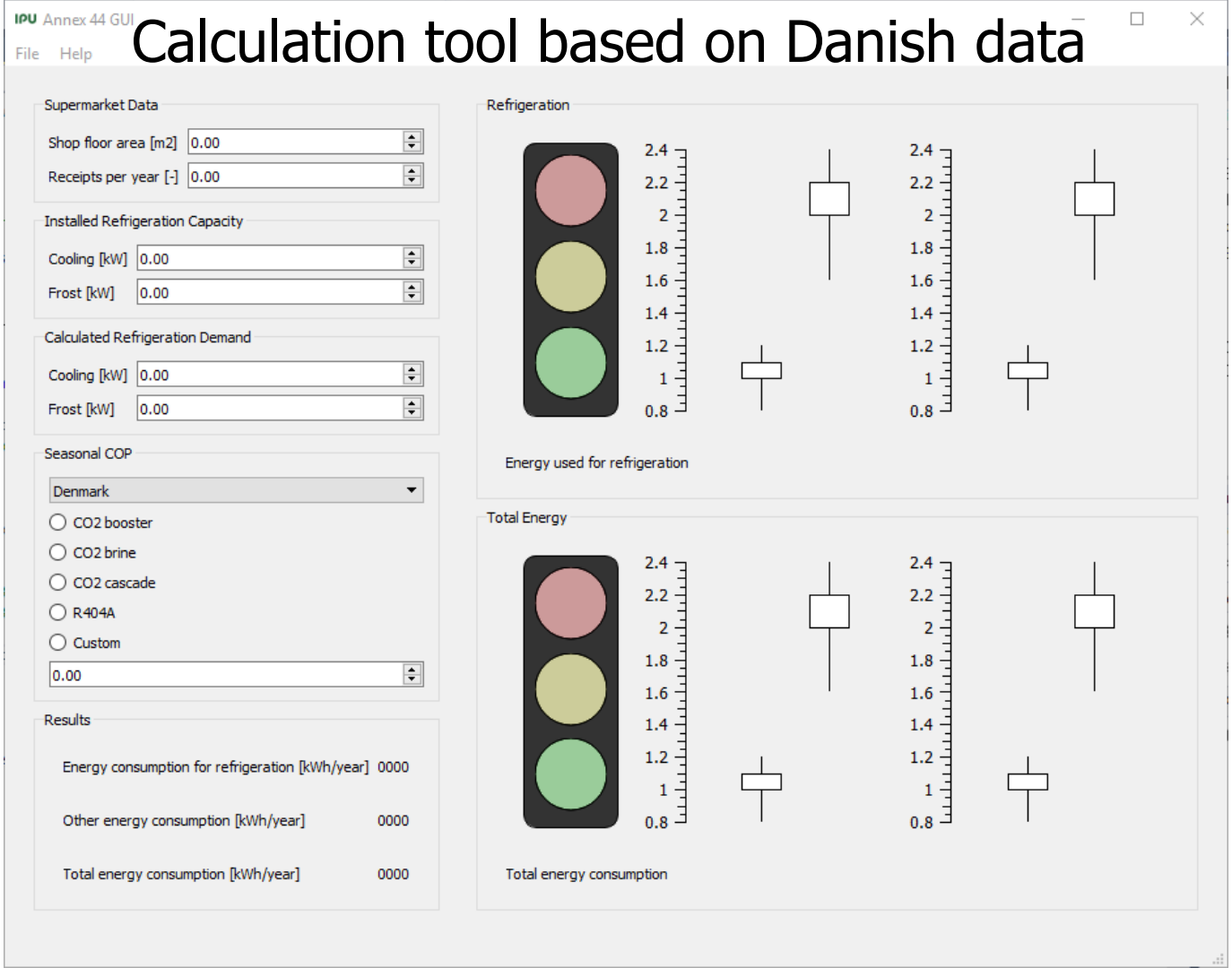
Green triangle is total

Orange diamond is non-refrigeration

Blue square is refrigeration

OBS: Receipts per year divided by sales area show no trend!

Calculation tool based on Danish data



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Energy performance will typically vary within a range of 30% for each of the categories:

- Building thermal envelope
- Systems for
  - Lighting
  - Heating
  - Air conditioning
  - Ventilation
  - Refrigeration
- Commissioning, balancing and servicing of each individual system
- Behavioural characteristics of employees and customers

There is a lot of potential for improving performance!

Consequence:

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Our models fail to predict energy performance due to the differences in:

- Commissioning, balancing and servicing of each individual system
- Behavioural characteristics of employees and customers

e.g. making a "poor" system perform better than the "best in class"

Important lesson:

- data sourced from auxiliary meters and sensors on subsystems cannot be trusted, unless
- there is a set-up in the company equivalent to energy management

Without the proper documentation, it cannot be evaluated if the measured values are comparable, especially not from one supermarket building to another. This is also true for other parameters such as refrigerated display area etc.

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Questions?

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And thanks to our partners

In Denmark:

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KTH (J. Arias, S. Sawalha)

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