Energy efficiency indices for large building stocks

Setting Energy Efficiency Benchmarks and Targets

The Contribution of Universities

Dr. Dario Cottafava

2nd UNISET
Energy Clustering Event
26/09/2016

Where we started?

Before 2014

A mountain of energy bills

Where we started?

Before 2014

Few excel tables

APRILE - EDISON					MAGGIO - EDISON				
F1	F2	F3	TOTALE	KwH/G	F1	F2	F3	TOTALE	KwH/G
7166,00	1688,00	3294,00	12148,00	404,93	6833,00	1744,00	3189,00	11766,00	379,55
5353,00	1033,00	1315,00	7701,00	256,70	5119,00	951,00	1313,00	7383,00	238,16
5985,00	3774,00	4492,00	14251,00	475,03	6036,00	3916,00	4375,00	14327,00	462,16
20955,00	10801,00	12919,00	44675,00	1489,17	20965,00	11574,00	11402,00	43941,00	1417,45
1157,00	322,00	585,00	2064,00	68,80	1236,00	343,00	625,00	2204,00	71,10
15308,00	8465,00	11894,00	35667,00	1188,90	15769,00	8944,00	10783,00	35496,00	1145,03
1272,00	370,00	698,00	2340,00	78,00	1360,00	396,00	746,00	2502,00	80,71
3913,00	3895,00	3935,00	11743,00	391,43	3943,00	4198,00	3991,00	12132,00	391,35
255,00	190,00	389,00	834,00	27,80	259,00	207,00	367,00	833,00	26,87
753,00	750,00	758,00	2261,00	75,37	759,00	808,00	768,00	2335,00	75,32
1396,00	1212,00	1254,00	3862,00	128,73	1420,00	1306,00	1276,00	4002,00	129,10
21517,00	9032,00	17271,00	47820,00	1594,00	21575,00	9414,00	15655,00	46644,00	1504,65
16091,00	6631,00	11324,00	34046,00	1134,87	16572,00	6970,00	9968,00	33510,00	1080,97
8501,00	3170,00	3487,00	15158,00	505,27	7056,00	2858,00	2813,00	12727,00	410,55
13851,00	4783,00	8762,00	28610,00	953,67	14169,00	5240,00	8648,00	28057,00	905,06
79765,00	50090,00	99931,00	229786,00	7659,53	81803,00	54234,00	93383,00	229420,00	7400,65
72633,00	32360,00	62013,00	167006,00	5566,87	74959,00	35450,00	59786,00	170195,00	5490,16
1475,00	356,00	610,00	2441,00	81,37	1506,00	339,00	535,00	2380,00	76,77

Where we started?

Before 2014

lots of money
to go without control

Electricity: over 32.76 GWh
(7.000.000€)
Gas: over 2082 TOE
(2.000.000 €)
per year

Re@Unito: the Energy Group

Date of birth: 02/2014

The Energy Group aims to monitor Unito's energy consumption, to foster energy efficiency, to reduce energy leakage and to increase renewable energy production.

Re@Unito: the Energy Group

Date of birth: 06/2014

The Energy Group aims to monitor Unito's energy consumption, to foster energy efficiency, to reduce energy leakage and to increase renewable energy production.

Let's start with the first energy audits and analyses

Re@Unito: the first energy analysis

2014

MARZO - EDISON				
F1	F2	F3	TOTALE	KwH/G
8408,00	2204,00	3317,00	13929,00	449,32
5532,00	1068,00	1359,00	7959,00	256,74
4899,00	2350,00	2898,00	7669,00	247,39
24722,00	14053,00	13616,00	52391,00	1690,03
1316,00	397,00	680,00	2393,00	77,19
17617,00	9454,00	11384,00	38455,00	1240,48
1450,00	425,00	745,00		
1566,00	1576,00	1555,00		
259,00	207,00	367,00		
327,00	329,00	324,00		
780,00	560,00	578,00		
24233,00	10797,00	17563,00		
19517,00	8159,00	11271,00		
11394,00	4656,00	4728,00		
15352,00	5491,00	8980,00		
86984,00	57495,00	98963,00		
79645,00	36221,00	60250,00		
1620,00	421,00	614,00		

APRILE - EDISON				
F1	F2	F3	TOTALE	KwH/G
7166,00	1688,00	3294,00	12148,00	404,93
5353,00	1033,00	1315,00	7701,00	256,70
5985,00	3774,00	4492,00	14251,00	475,03
20955,00	10801,00	12919,00	44675,00	1489,17
1157,00	322,00	585,00	2064,00	68,80
15308,00	8465,00	11894,00	35667,00	1188,90
1272,00	370,00	698,00	2340,00	78,00
3913,00	3895,00	3935,00	11743,00	391,43
255,00	190,00	389,00	834,00	27,80
753,00	750,00	758,00	2261,00	75,37
1396,00	1212,00	1254,00	3862,00	128,73

Re@Unito: the first energy analysis

2014

RICA UNITO (ALTA TENSIONE E MEDIA TENSIONE)

F1	F2	SUPERFICE	ENERGIA ATTIVA 2014 TOTALE F1	TOTALE F2	TOTALE F3	TOTALE ANNO
8408,00	2204,00	8780,450621	346847	131589	210352	688788
5532,00	1068,00	9873,388977	191800	111183	117451	420434
4899,00	2350,00	7440,591059	169942	56040	96188	322170
24722,00	14053,0(	9873,388977	108862	39485	40634	188981
1316,00	397,00	0	104186	41660	48886	194732
17617,00	9454,00	0	50970	27598	48755	127323
145						1748
156						9992
25						4695
32						1108
78						7512
242						1361
195						1489,17
113						68,80
153						1188,90
869						78,00
796						391,43
162						27,80
						75,37
						128,73

TOTALE CO

SEDE	POD	TENSIONE
TORINO, CORSO SVIZZERA 185	IT020E00189426	380 Volt
TORINO, PIAZZA BERNINI 12	IT020E00168202	380 Volt
TORINO, CORSO MASSIMO D'AZEGLIO 42	IT020E00311533	380 Volt
TORINO, VIA MASSIMO MONTANO 1	IT020E00168205	380 Volt
TORINO, CORSO MASSIMO D'AZEGLIO 15	IT020E00066865	380 Volt
TORINO, CORSO REGIO PARCO 142	IT020E00555148	380 Volt
TORINO, VIA GABRIELE CHIABRERA 37	IT020E00327838	380 Volt
TORINO, VIA VERDI 25	IT020E00047109	380 Volt
TORINO, VIA BAVA 31	IT020E00635951	380 Volt
TORINO, VIA CESARE BENEVELLO 3	IT020E00047108	380 Volt
TORINO, VIA SANT'OTTAVIO 19	IT020E00309177	380 Volt
TORINO, VIA SANT'OTTAVIO 50	IT020E00305517	380 Volt

Re@Unito: the first energy analysis

2014

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			ENERGIA ATTIVA 2014			
F1	F2	SUPERFICE	TOTALE F1	TOTALE F2	TOTALE F3	TOTALE ANNO
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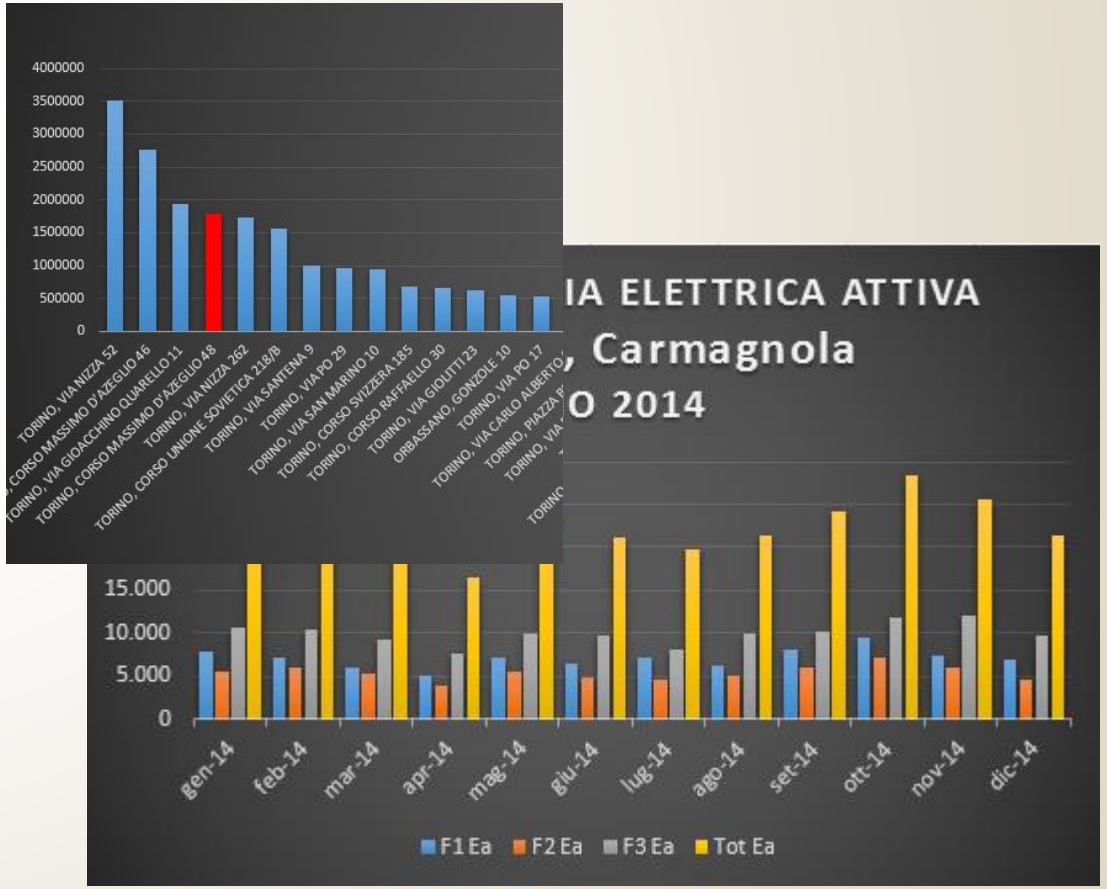
1316,00	397,00	0	104186	41660	48886	194732
17617,00	9454,00	0	50970	27598	48755	127323
1450,00	425,00	2467,346013	52523	47827	51398	151748
1566,00	1576,00	5556,677502	38645	34865	36482	109992
259,00	207,00	2581,820518	74959	13467	16269	104695
327,00	329,00	5556,677502	42929	11710	19469	74108
780,00	560,00	1326,315086	19391	15787	22334	57512
24233,00	10797,0(	1148,690089	17260	14127	19974	51361
19517,00	8159,00	11271,00	20955,00	10801,00	12919,00	44675,00	1489,17
11394,00	4656,00	4728,00	1157,00	322,00	585,00	2064,00	68,80
15352,00	5491,00	8980,00	15308,00	8465,00	11894,00	35667,00	1188,90
86984,00	57495,00	98963,00	1272,00	370,00	698,00	2340,00	78,00
79645,00	36221,00	60250,00	3913,00	3895,00	3935,00	11743,00	391,43
1620,00	421,00	614,00	255,00	190,00	389,00	834,00	27,80
			753,00	750,00	758,00	2261,00	75,37
TORINO, VIA CESARE BEN			1396,00	1212,00	1254,00	3862,00	128,73
TORINO, VIA SANT'OTTA							
TORINO, VIA SANT'OTTAVIO 50			IT020E00305517		380 Volt		



Re@Unito: the first energy analysis

2014

RICA UNITO (ALTA TENSIONE E MEDIA TENSIONE)

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17617,00	9454,00	0	50970	27598	48755	127323
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1566,00	1576,00	5556,677502	38645	34865	36482	109992
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24233,00	10797,0(	1148,690089	17260	14127	19974	51361
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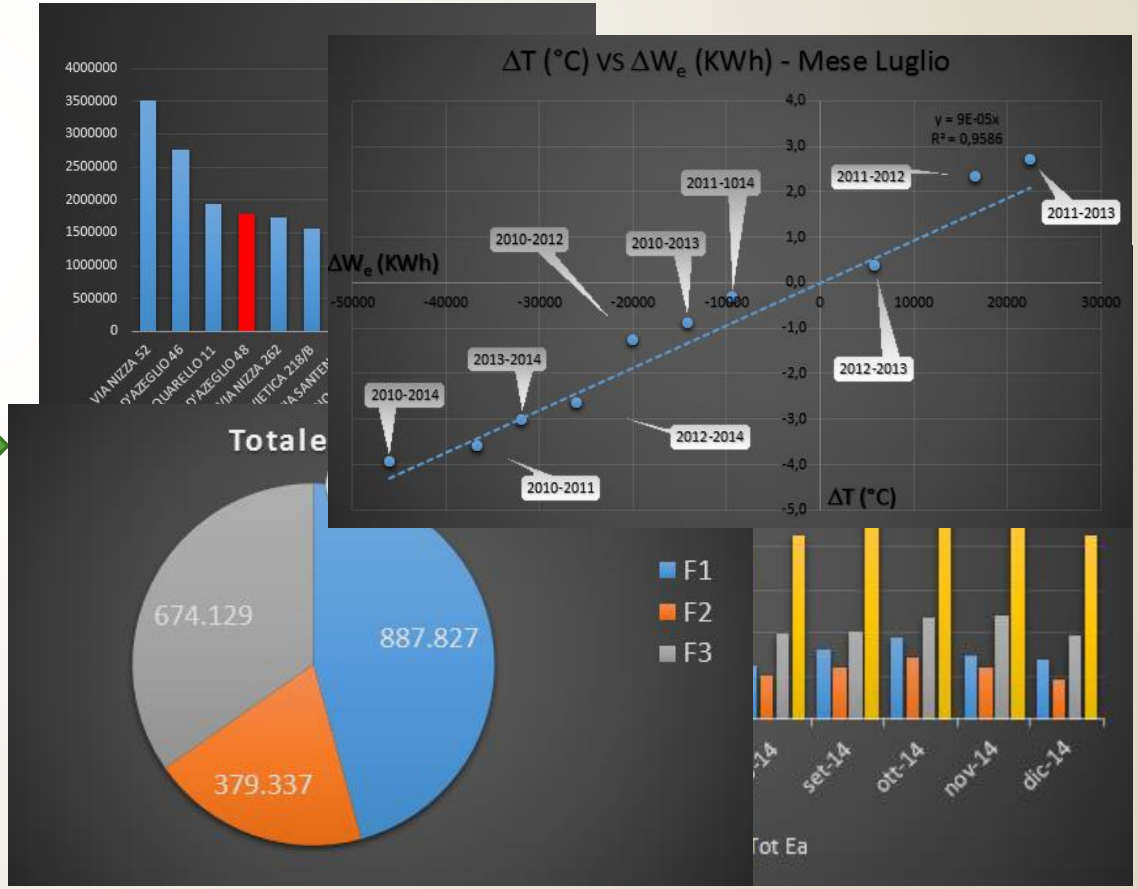
11394,00	4656,00	4728,00	1157,00	322,00	585,00	2064,00	68,80
15352,00	5491,00	8980,00	15308,00	8465,00	11894,00	35667,00	1188,90
86984,00	57495,00	98963,00	1272,00	370,00	698,00	2340,00	78,00
79645,00	36221,00	60250,00	3913,00	3895,00	3935,00	11743,00	391,43
1620,00	421,00	614,00	255,00	190,00	389,00	834,00	27,80
			753,00	750,00	758,00	2261,00	75,37
TORINO, VIA CESARE BEN			1396,00	1212,00	1254,00	3862,00	128,73
TORINO, VIA SANT'OTTA							
TORINO, VIA SANT'OTTAVIO 50			IT020E00305517		380 Volt		



Ok, wait a minute

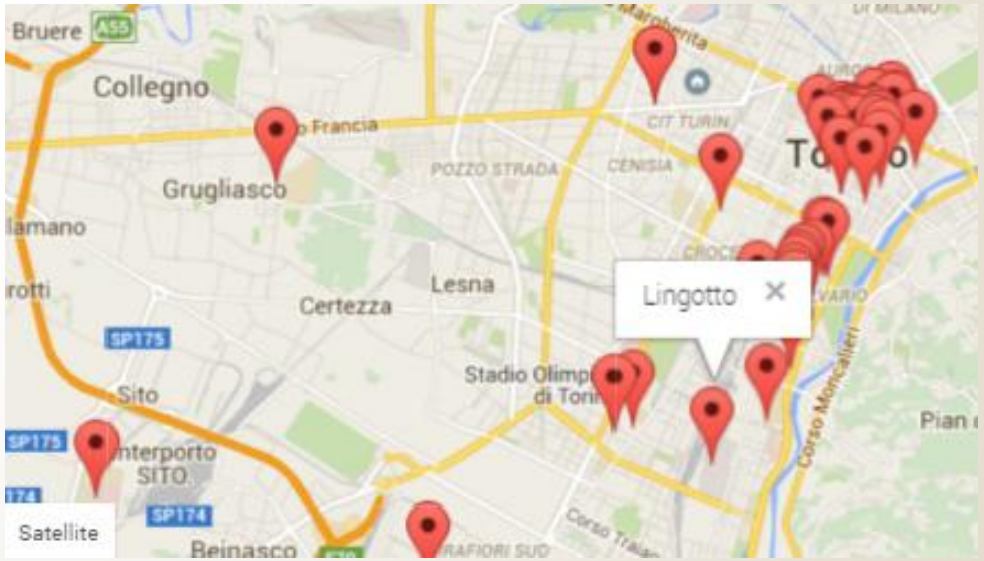
Maybe, we need another approach…

Re@Unito: Unito at a glance

2014

An overview

Building Stock	•Over one hundred buildings •Over 514387 square meters
Annual Energy Consumption	•Over 32.76 GWh / 7.000.000€ (Electric) •Over 2082 TOE / 2.000.000 € (Gas)
Users	•Over 66.000 Students •Over 2000 Professor & Researchers •Over 1700 Administrative Staffs



Re@Unito: Unito at a glance

UNITO's building stock

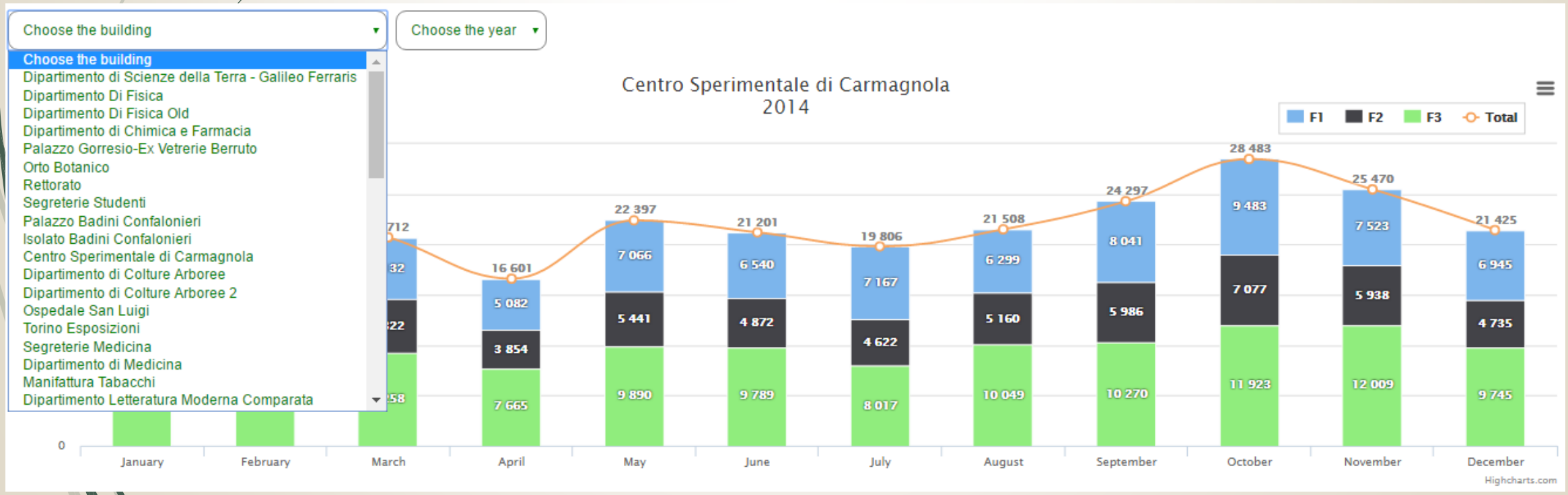
Period of construction
• Rettorato (1713) • Palazzo Campana (1675) • Physics Department (end of XIXth) • Palazzo Nuovo (1966) • Grugliasco (1999) • Campus Luigi Einaudi (2012)

Functions
• Administrative Offices (EX: Palazzo degli Stemmi) • Humanities Departments (EX: Palazzo Nuovo) close at 8:00 PM • Hospitals: (EX: Molinette) • Science Departments: (EX: Biotech, Physics, Chemistry) host several laboratories working 24h/24h • Botanical Garden, Museum, libraries, …

1st javascript prototype

2015

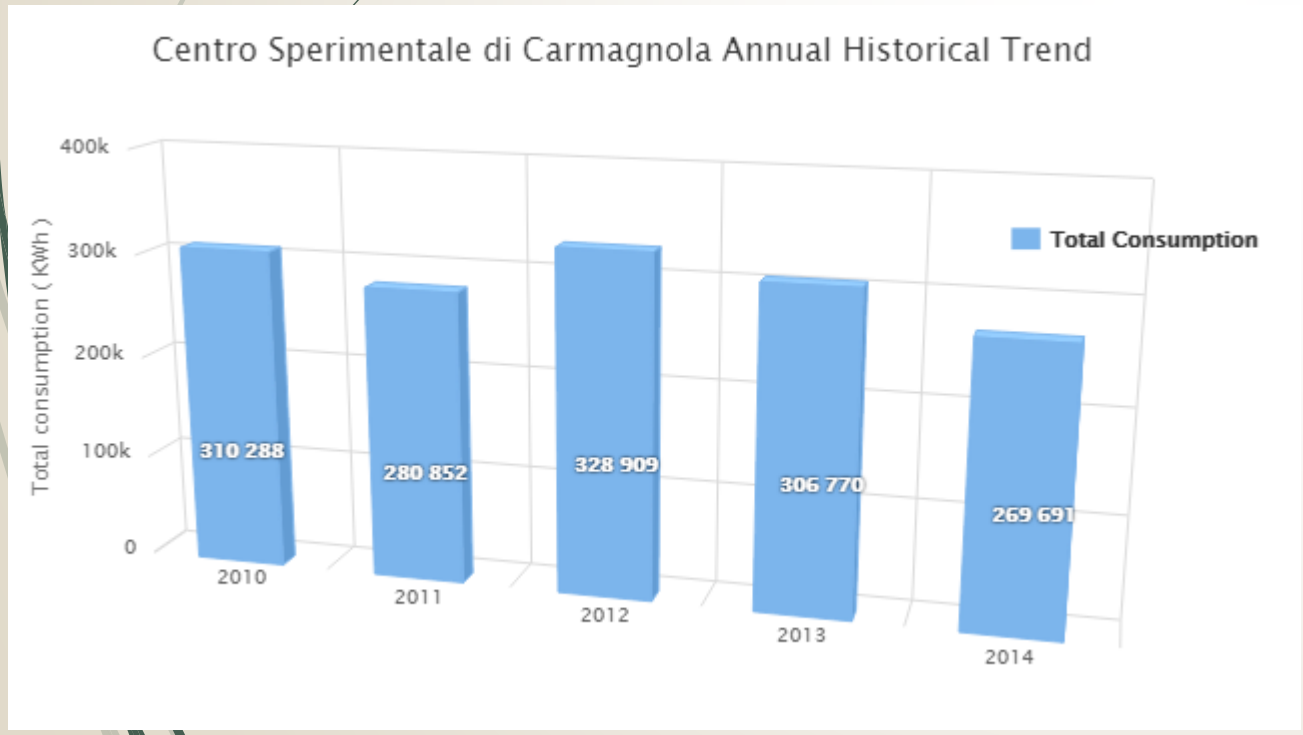
Development of js script to analyse single building energy consumption …

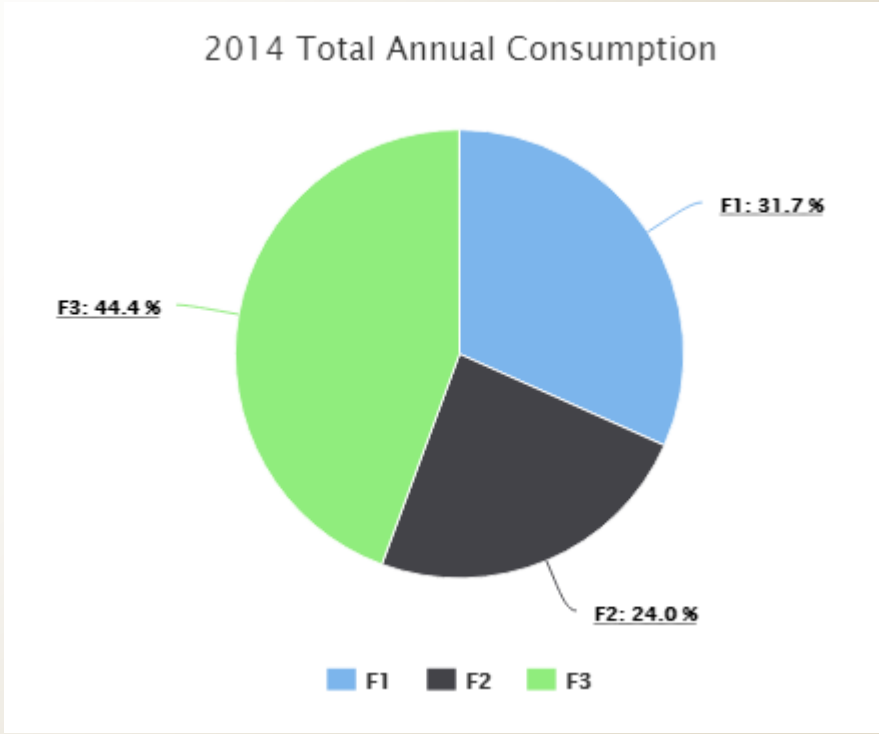


1st javascript prototypes

2015

… and to compare different years and building consumption





2015

Ok, well.

Now, it's easier to write energy reports and to identify the most inefficient buildings

Energy reports

2015

RE@UNITO

Il Piano di Risparmio Energetico

Dell'Università degli Studi Di Torino

FOCUS BIOTECNOLOGIE

Energy reports

2015

RE@UNITO

Il Piano di Risp

Dell'Universi

To

FOCUS BIO

RE@UNITO

Il Piano di Risparmio Energetico

Dell'Università degli Studi Di Torino

FOCUS MATEMATICA

Energy reports

2015

RE@UNITO

Il Piano di Risparmio Energetico

Dell'Università degli Studi Di

Torino

FOCUS CHIMICA

RE@U

Il Piano di Rispar

Dell'Università

Tori

FOCUS ECONOMIA

ergetico

tudi Di

FOCUS MATEMATICA

2015

…… !!!!???!!!

Maybe, we need more people…

OpenData, thesis and energy audit

Need to engage directly the users of each building

OpenData
a «common»
to improve sustainability

Need to spend a lot of time to identify energy wasting

Student's projects
(bachelor and master)
to conduct energy audits

UniToGO: Unito Green Office

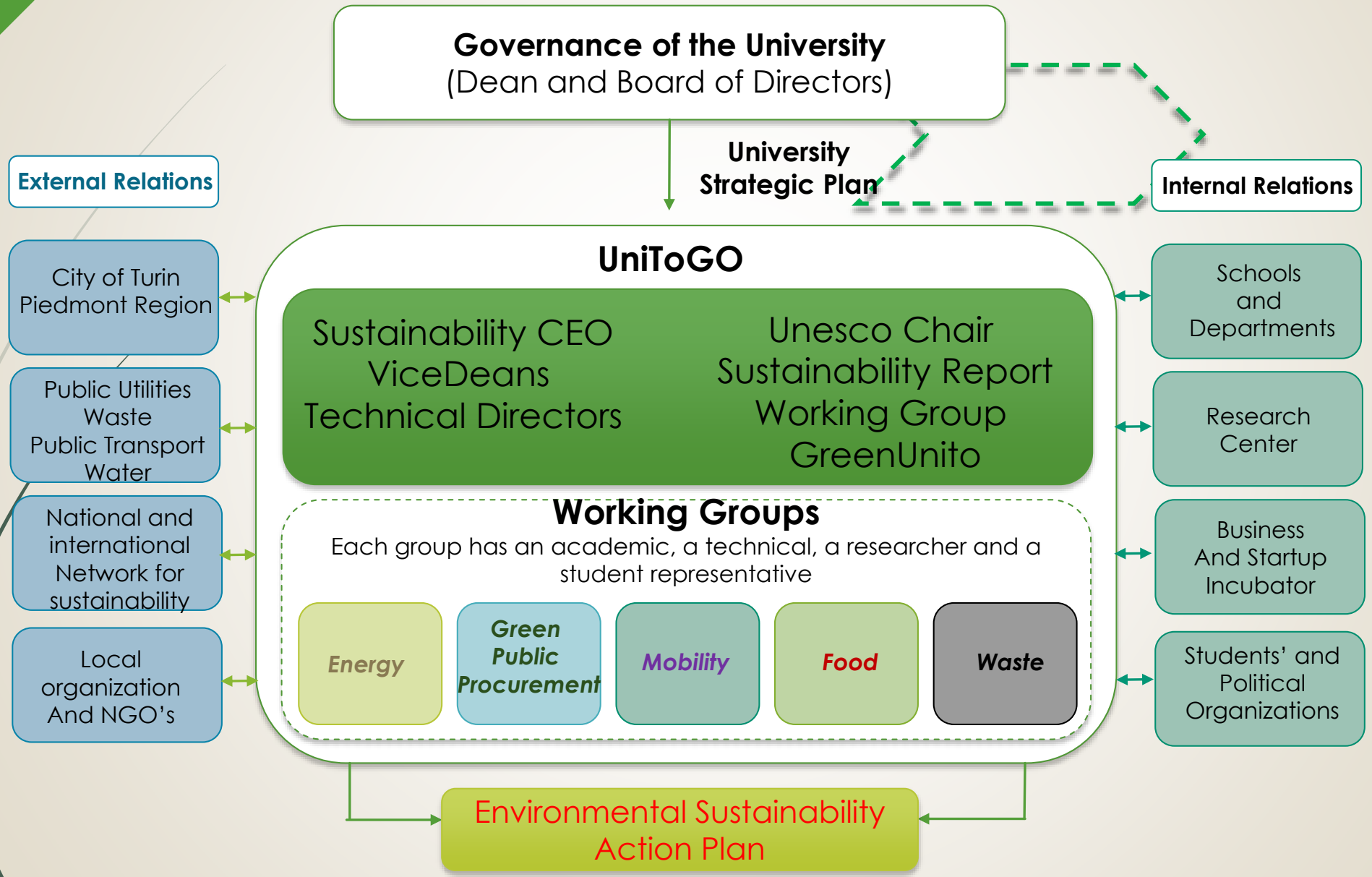
Date of birth: 05/2016

UniToGO is an interdisciplinary network within the University of Turin, organised in 5 Working Groups formed by academic and technical staff as well as students.

UniToGo coordinates and promotes all activities and initiatives about sustainability.

UniToGO elaborates an "Environmental Sustainability Action Plan"

The structure of the Unito Green Office



UniToGO: action plan

1st aim of each Group
Define an action plan

Necessity of proper energy efficiency indices

Necessity of a proper approach to monitor historical trends

A methodology for the energy performance classification of residential building stock on an urban scale, Giuliano Dall'O'

Energy Efficiency indices: general considerations

2016

The most general definition of an **Energy Efficiency Index*** is:

$$EEI = \frac{E}{\Lambda}$$

where ***E* = «Energy Consumption»** and **Λ = «Factor related to the Energy Consumption»**

1. **The factor *E*** can be related to:
   A. The Electrical Consumption E_{kwh} (Kwh);
   B. The Gas Consumption E_{gas} (m^3 of gas);
2. **The factor Λ** can be related to:
   1. The Surface of the building Λ_{m2} (m^2);
   2. The number of Users Λ_{users} (#users);
   3. The Degree Days Λ_{DDx} (Degree Days). DDx refers to different approaches;
   4. Any other factors.

* Energy efficiency index as an indicator for measuring building energy performance: A review, 2015, Nur Najihah Abu Bakar

Energy Efficiency indices: degree-day method

2016

The degree-day method relates the energy consumption with the average outdoor temperature and/or humidity. It can be used to compare the performance in different years, e.g.

$$EEI_{year,\ Kwh,\ DDx} = \sum_{i=6}^{9} \frac{E_{i,\ Kwh}}{\Lambda_{i,DDx}}$$

Indeed, the heating and the ventilating systems are strongly affected by the outdoor weather conditions.

Here the main limitation is that energy consumption is not saturated by HVAC systems.

In this study, two different $\Lambda_{i,DDx}$ coefficients have been adopted:

1. **Mean Temperature Index**: $\Lambda_{i,DDmax} = \sum_{j=1}^{30}(T_{j,\ av} \_ T_{Comfort})$ where $T_{j,\ av}$ = «Daily average temperature» and $T_{Comfort} = 24°C$;

2. **Humidex Index***: $\Lambda_{i,DDHumidex} = \sum_{j=1}^{30} T_{j,\ av} + \frac{5}{9}\left(6.11 * \frac{HU_{j,\%}}{100} * 10^{\frac{7{,}5 * Tj_{av}}{237{,}7 + Tj_{av}}} - 10\right)$ where $HU_{j,\ \%}$ = «Daily Average Relative Humidity»;

* J.M. Masterton, 1979, A Method of Quantifying Human Disconfort Due To Excessive Heat and Humidity

Energy Efficiency indices: weekday VS night/holiday consumption

2016

A useful approach is based on monitoring the consumption during the week working hours and during the night/weekend/holiday.

$$EEI_{year,\,Kwh,\,night/day} = \frac{1}{N}\sum_{i=1}^{N} EEI_{i,\,Kwh,\,night/day} = \frac{1}{N}\sum_{i=1}^{N} \frac{Ei_{,\,Kwh,\,night}}{E_{i,\,Kwh,\,day}}$$

where $E_{i,\,Kwh,\,night}$ = «Kwh during night/weekend/holiday, $E_{i,\,Kwh,\,day}$ = «Kwh during day» for month *i* and N = 12 is the number of months.

This ratio simply reveals if the heating plants, the lighting and all other possible electrical loads has been properly set.

1. If $EEI_{i,\,Kwh,\,night/day} > 1 \Rightarrow Ei_{,\,Kwh,\,night} > E_{i,\,Kwh,\,day}$
2. If $EEI_{i,\,Kwh,\,night/day} < 1 \Rightarrow Ei_{,\,Kwh,\,night} < E_{i,\,Kwh,\,day}$

Building the proper ranking

2016

August

Rank	Building	Value
1	Biotecnologie	16.95 KWh/m2
2	Dipartimento Di Fisica	13.17 KWh/m2
3	Orto Botanico	12.73 KWh/m2
4	Ex Edilscuola	8.84 KWh/m2
5	Lingotto	8.31 KWh/m2
6	Campus Luigi Einaudi	8.24 KWh/m2
7	Palazzo degli Stemmi	6.84 KWh/m2
8	Dipartimento di Economia	6.40 KWh/m2
9	Dipartimento Di Informatica	6.39 KWh/m2
10	Ospedale San Luigi	6.01 KWh/m2

January

Rank	Building	Value
9	Dipartimento Di Informatica	6.51 KWh/m2
10	Campus Luigi Einaudi	6.45 KWh/m2
16	Centro Sperimentale di Carmagnola	4.94 KWh/m2
17	Ospedale San Luigi	4.72 KWh/m2
18	Dip. di Scienze Sociali	4.69 KWh/m2

Different month

⇓

Different ranking

Building the proper ranking

2016

KWh / m^2

KWh / users

Rank	Building	Value
1	Biotecnologie	19.4 KWh/m2
2	Dipartimento Di Fisica	14.72 KWh/m2
3	Orto Botanico	13.6 KWh/m2
4	Lingotto	11.45 KWh/m2
5	Campus Luigi Einaudi	11.03 KWh/m2
6	Dipartimento di Economia	10.4 KWh/m2
7	Ex Edilscuola	9.24 KWh/m2
8	Palazzo degli Stemmi	8 KWh/m2
9	Dipartimento Di Informatica	7.9 KWh/m2
10	Dipartimento di Chimica e Farmacia	7.8 KWh/m2

Rank	Building	Value
3	Dipartimento Di Fisica	217.6 KWh/Users
4	Dipartimento di Chimica e Farmacia	183.43 KWh/Users
5	Farmacologia	156.06 KWh/Users
13	Dipartimento Di Informatica	47.35 KWh/Users
14	Campus Luigi Einaudi	44.56 KWh/Users
15	Ospedale San Luigi	30.46 KWh/Users

Different Λ_i coefficient

⇓

Different ranking

Building the proper ranking

Kwh_{night} / Kwh_{day}

Rank	Building	Value
43	Torino Esposizioni	0.6808 KWh_night/KWh_day
44	Campus Luigi Einaudi	0.6754 KWh_night/KWh_day
45	Dipartimento Di Informatica2	0.64 KWh_night/KWh_day

A completely different ranking

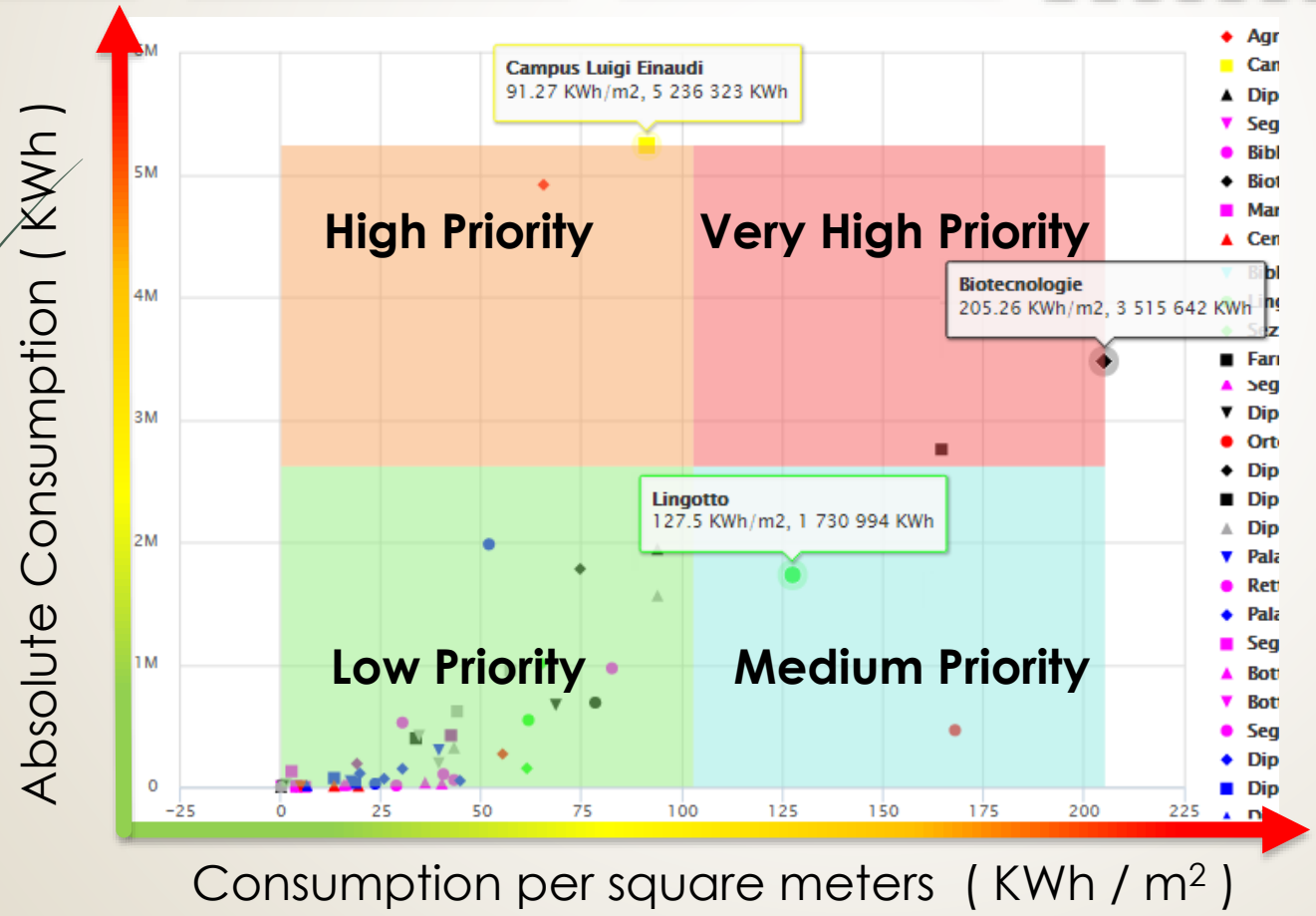
Building the proper ranking

…… !!!!???!!!

Maybe, we need some analysis tools…

Clustering building functions: the scatter method analysis

2016

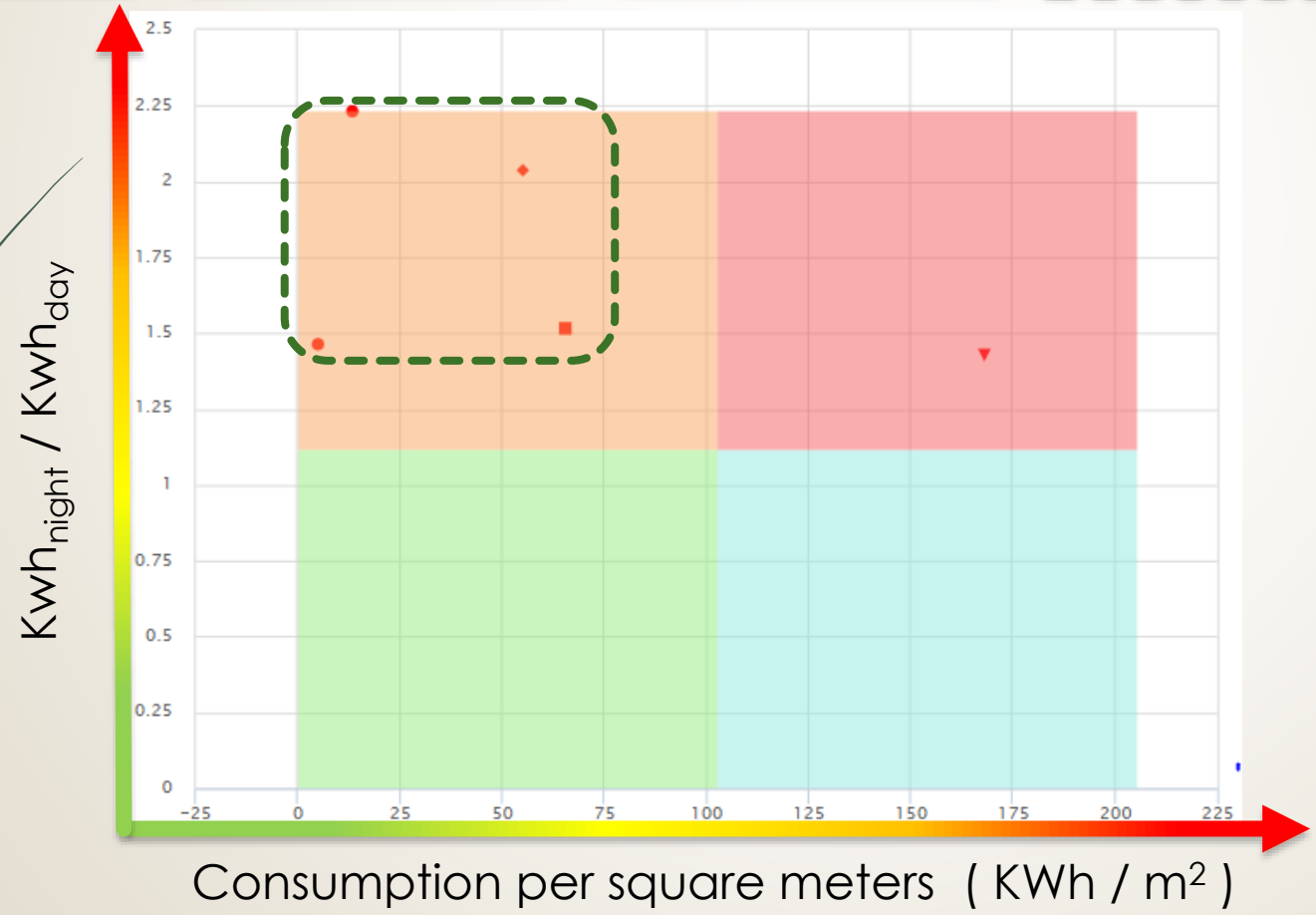


* The Database of actual Energy Consumption as a tool to analyze and plan energy retrofit actions in large building stocks, Federica Ariaudo
* True Green and Sustainable University Campuses? Toward a Clusters Approach, 2016, Giulia Sonetti

Clustering building functions: the scatter method analysis

2016

Agrarian Buildings

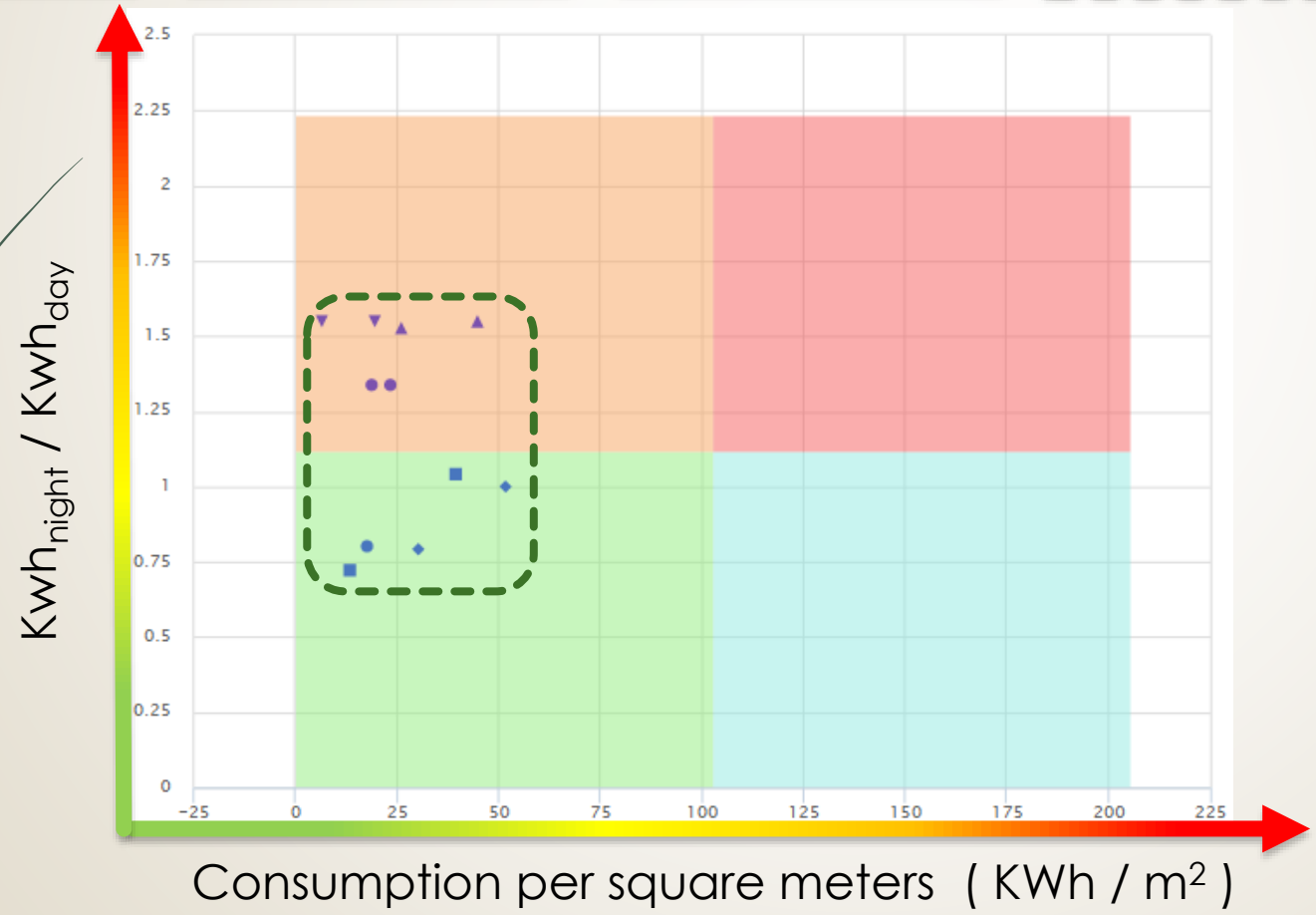


- Dipartimento di Colture Arboree
- Centro Sperimentale di Carmagnola
- Agraria
- Centro di apicoltura Don Angeleri
- Orto Botanico
- Dipartimento di Colture Arboree 2

1. HIGH consumption at night
2. LOW consumption per m^2

Clustering building functions: the scatter method analysis

2016



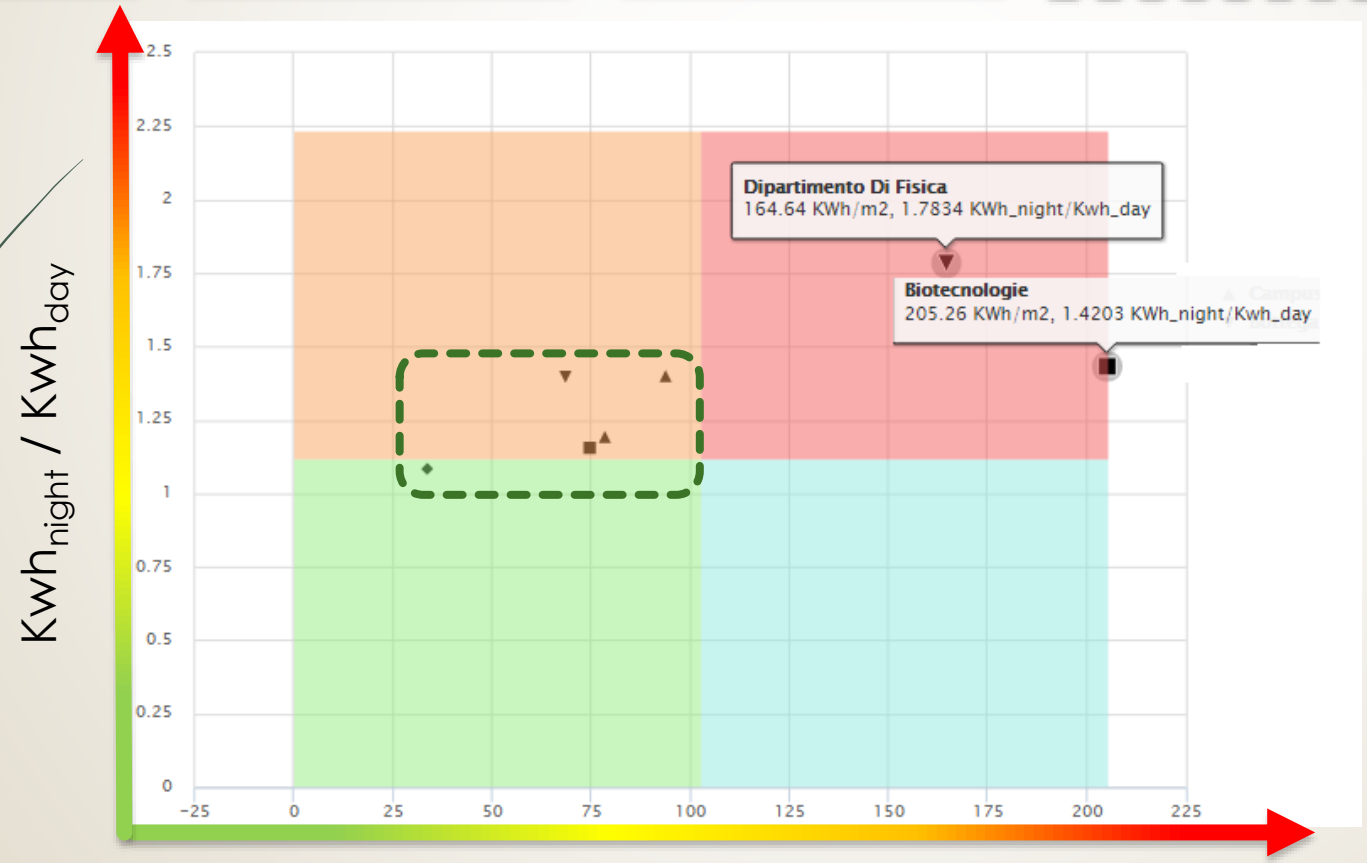
Humanities Buildings

- Psicologia
- Palazzo Nuovo
- Palazzo Badini Confalonieri
- Dip. di Scienze Sociali
- Palazzo Lionello Venturi 2
- Dipartimento Letteratura Moderna Comparata 2
- Palazzo Gorresio–Ex Vetrerie Berruto
- Palazzo Lionello Venturi
- Dip. di Scienze Giuridiche
- Dipartimento Letteratura Moderna Comparata
- Ex Istituto Galvani

1. MEDIUM consumption at night
2. LOW consumption per m^2

Clustering building functions: the scatter method analysis

2016



Scientific Buildings (with lab)

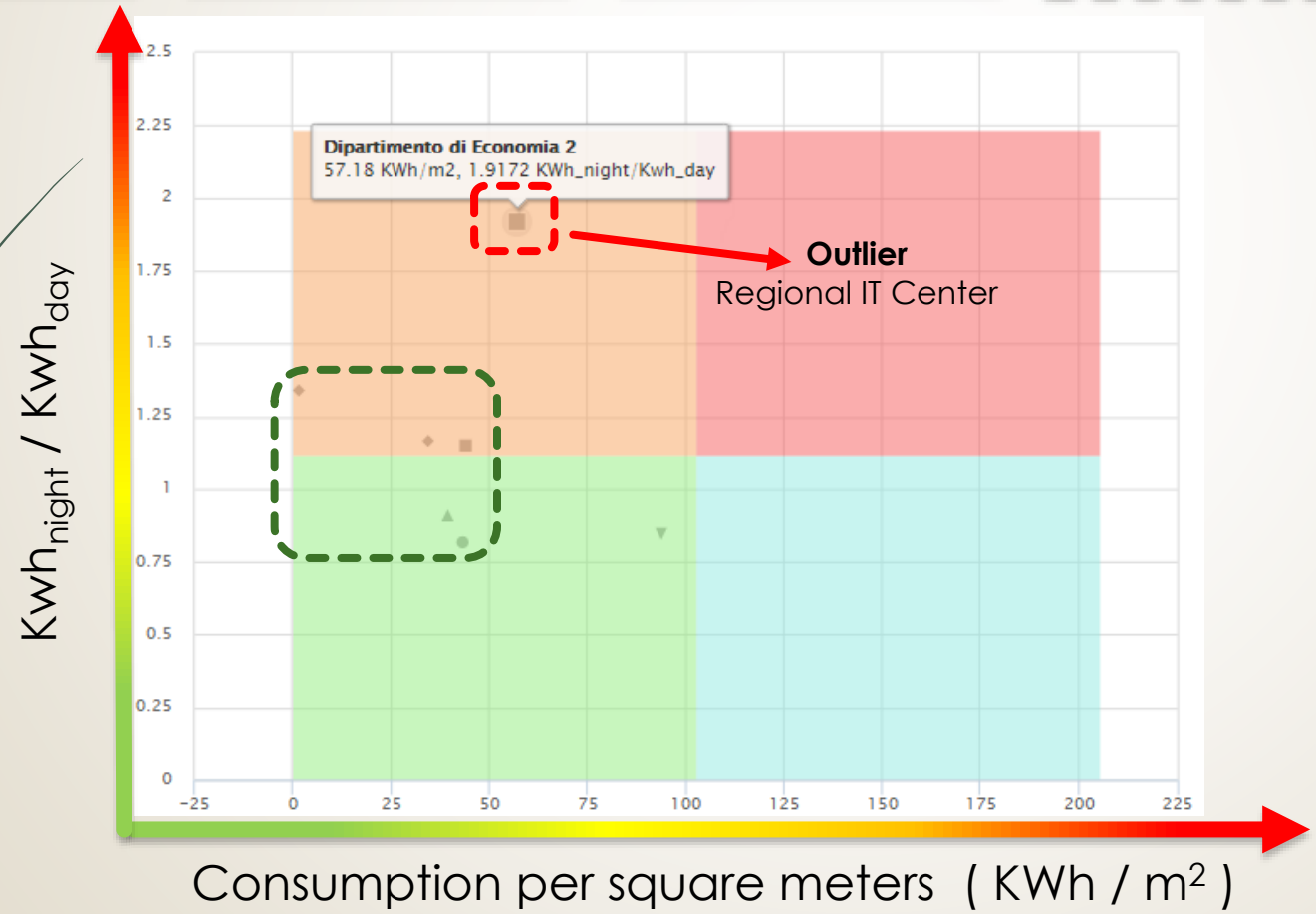
- Farmacologia
- Biotecnologie
- Ex Edilscuola
- Dipartimento di Medicina
- Dipartimento Di Informatica2
- Dipartimento Di Fisica Old
- Dipartimento di Chimica e Farmacia
- Dipartimento Di Informatica
- Dipartimento Di Fisica

1. MEDIUM consumption at night
2. MEDIUM consumption per m^2

Clustering building functions: the scatter method analysis

2016

Scientific Buildings (without lab)

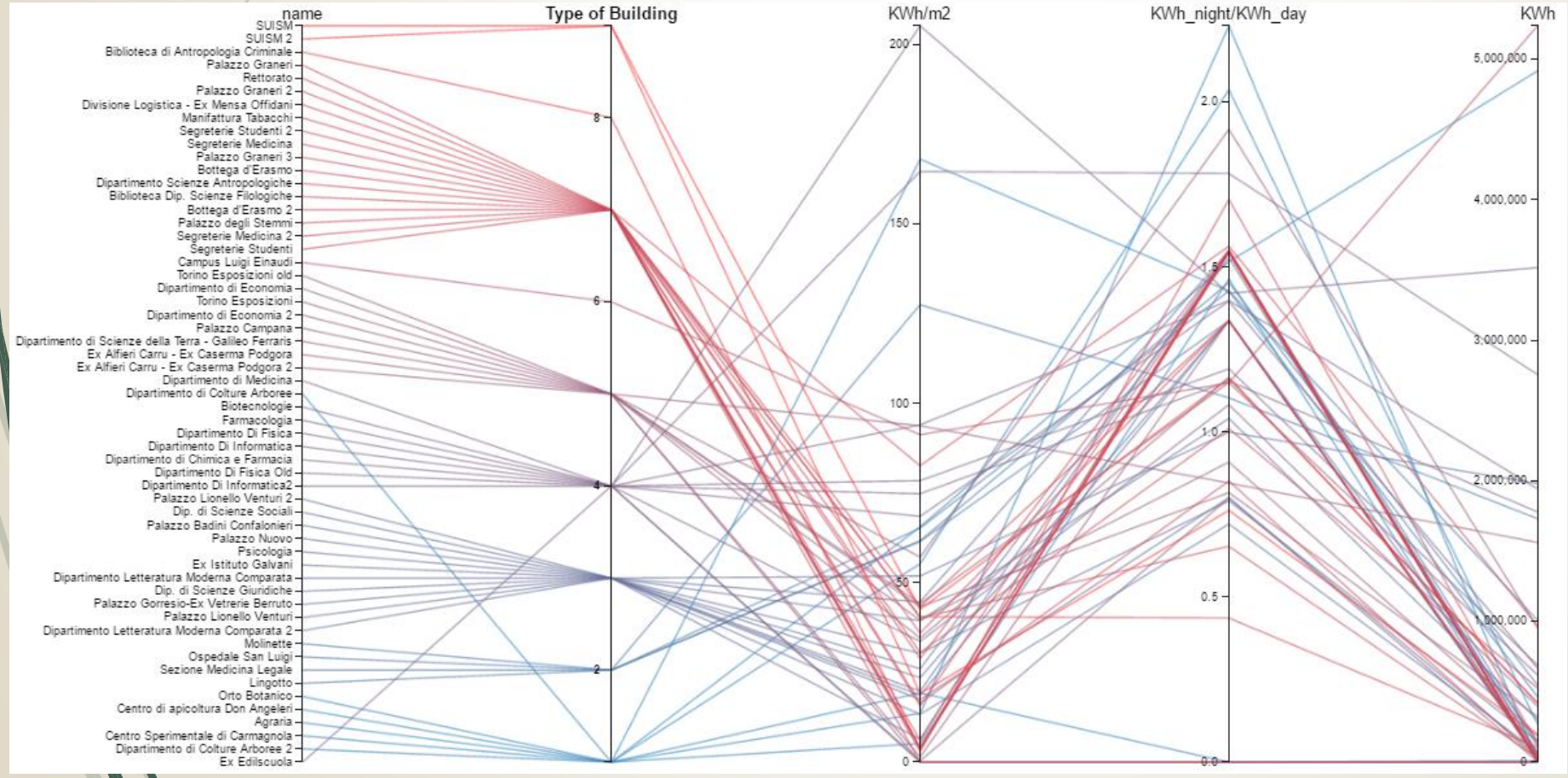


- Dipartimento di Scienze della Terra – Gal
- Palazzo Campana
- Dipartimento di Economia 2
- Torino Esposizioni
- Dipartimento di Economia
- Torino Esposizioni old
- Ex Alfieri Carru – Ex Caserma Podgora 2
- Ex Alfieri Carru – Ex Caserma Podgora

1. LOW consumption at night
2. LOW consumption per m^2

Clustering building functions: multi dimension analysis

2016



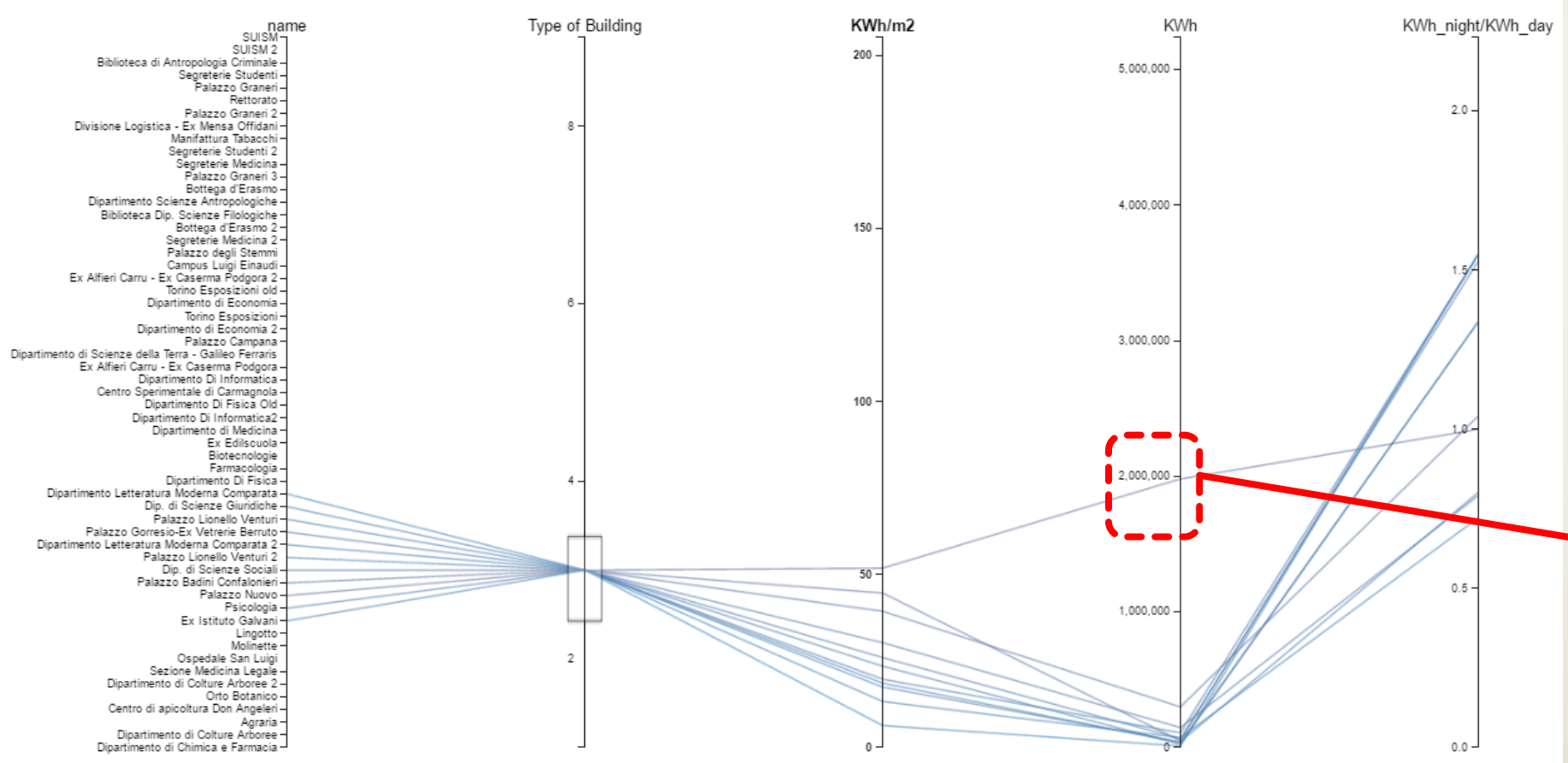
All Unito's building stock

Clustering building functions: multi dimension analysis

Too messy?

Clustering building functions: multi dimension analysis

2016

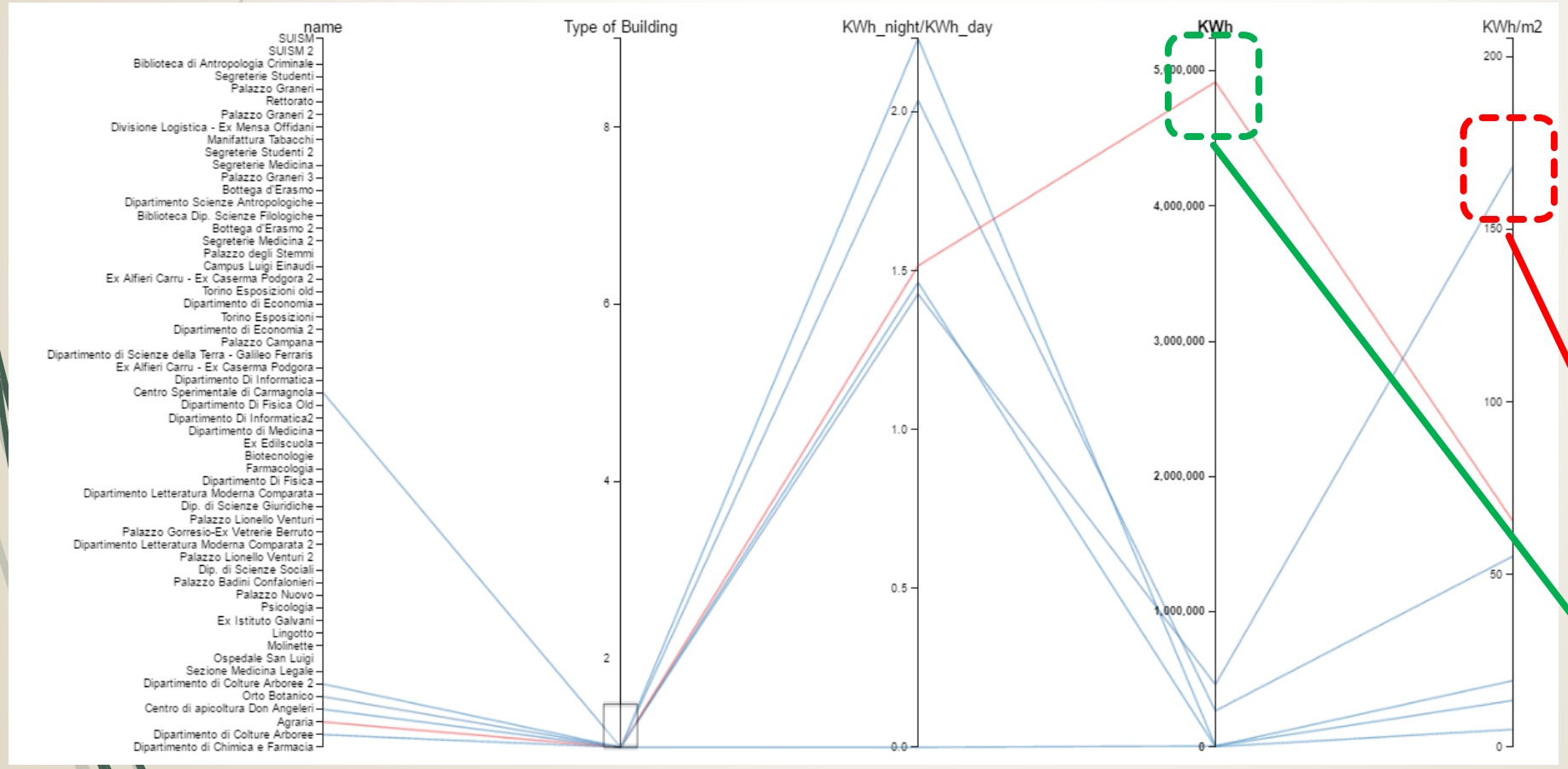


Humanities buildings

Outlier
Palazzo Nuovo
(biggest building)

Clustering building functions: multi dimension analysis

2016



Agrarian buildings

Outliers

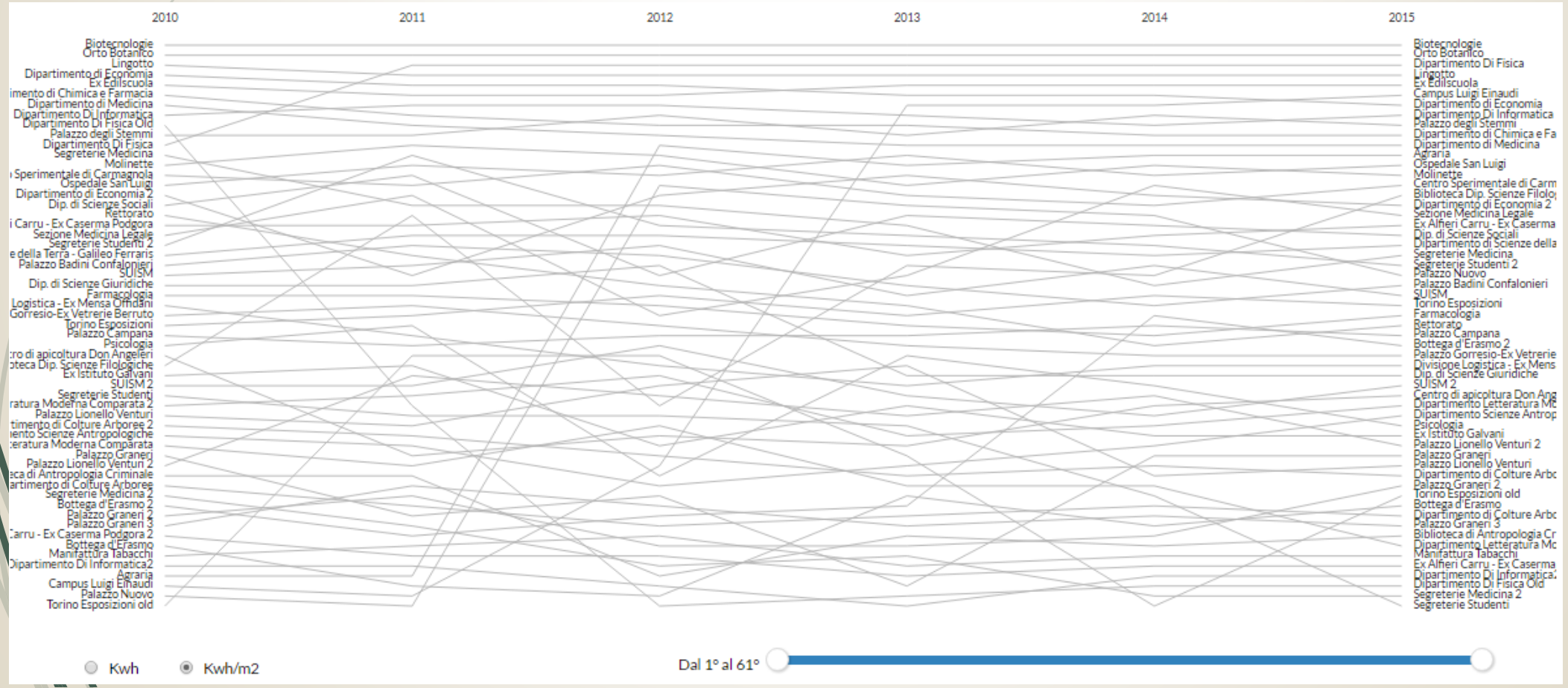
Botanical Garden

and

Agraria Campus

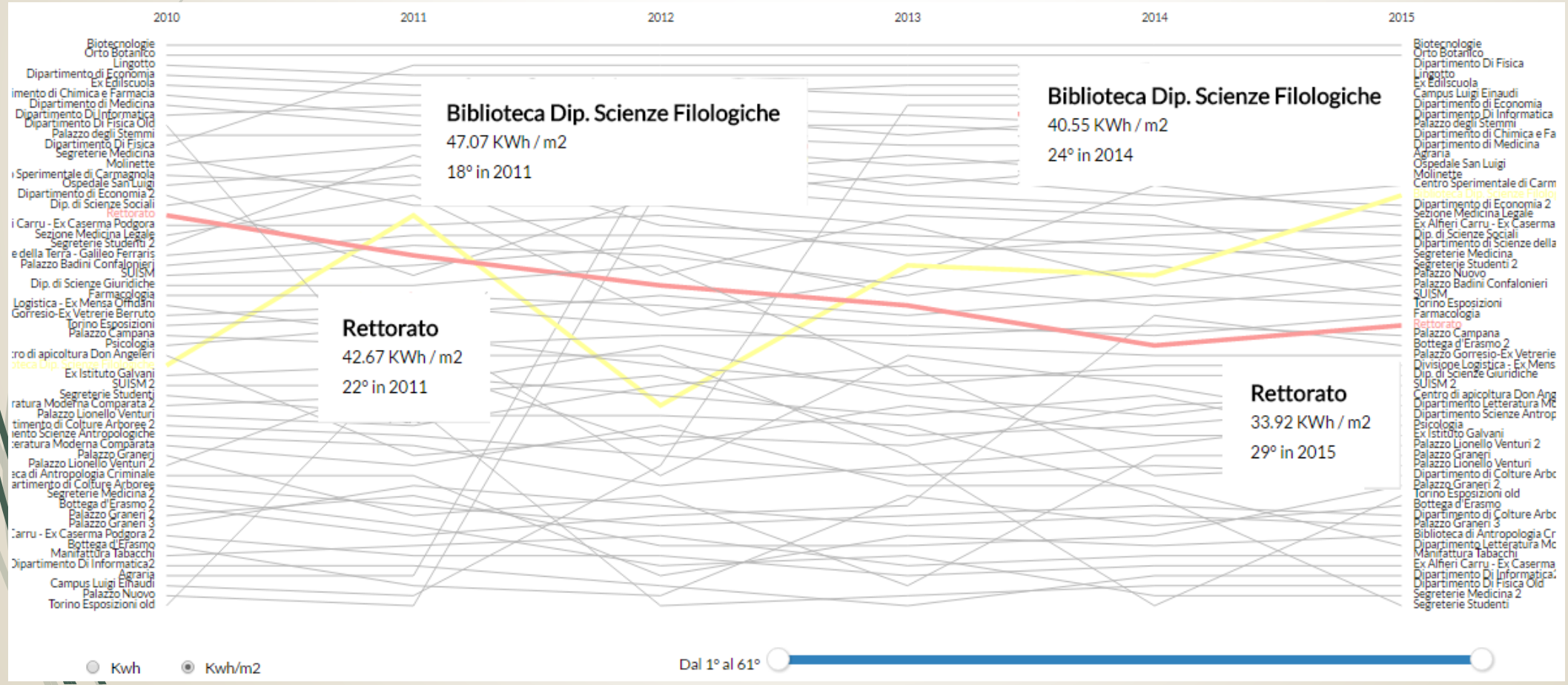
Monitoring historical trends: annual consumption per square meters

2016



Monitoring historical trends: annual consumption per square meters

2016



Towards a well-design platform

All the analyses presented are based on monthly electrical bills which can be quickly recovered through an online open source platform.
We observe that in order for EEI to be helpful in the energy management of a large building stock

There are some general simple tips and suggestions which must be pointed out as results of this work in order to use EEIs.

1. A precise definition of «edges» and «thresholds» for different types of buildings is necessary
2. One needs to know precisely the functions and the main electrical loads for any building
3. Different approaches (i.e. scatter method and multi dimension analysis) can be used to define clusters of building

THANK YOU
FOR
YOUR ATTENTION

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