TEESlab
University of Piraeus Research Center

Exploring the energy-saving potential and cost-effectiveness of energy efficiency measures in the residential sector in Europe

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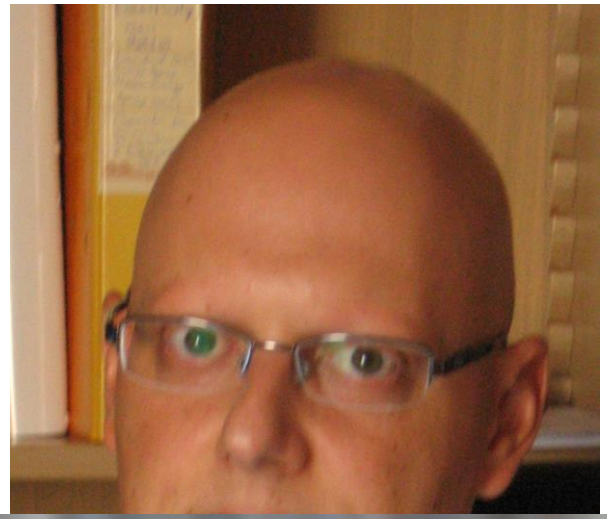


Introduction & Problem statement (1/2)

Buildings account for **40%** of the final energy consumption in the EU, with the **residential sector** being responsible for **two thirds** of this consumption.

85% of the buildings in the EU have been constructed **before 2001**.

85% - 95% of the **current buildings** will continue to **exist up to 2050** with most of them not being energy efficient.

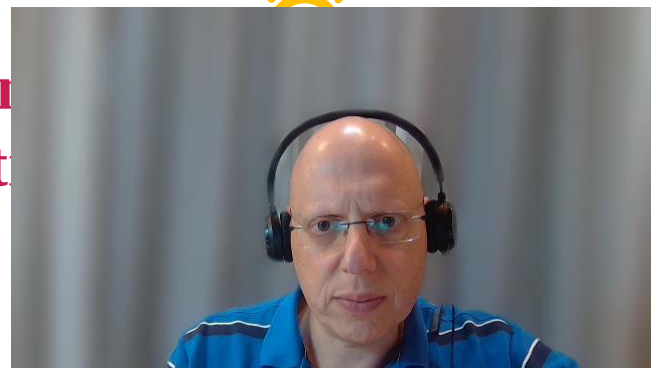
Need for smarter & more energy-efficient buildings

30 million consumers struggled to keep their homes **adequately** warm in 2019.

Annual renovation rate of the building stock varying from **0.4** to **1.2%**.

Building sector has significant room for decarbonisation.

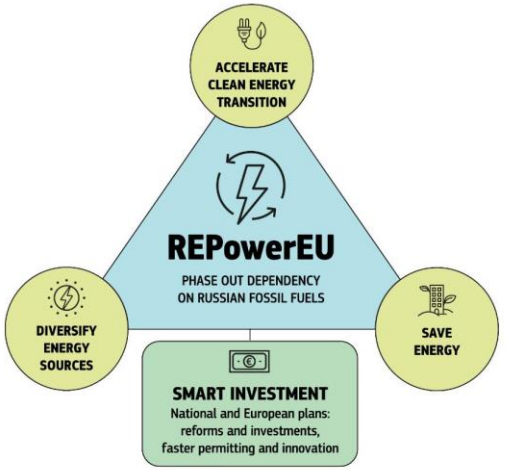
Need of i
act



INTRODUCTION & PROBLEM STATEMENT (2/2)

Towards the decarbonisation of the European residential sector…

- '**Renovation Wave**' strategy - objective to **at least double the annual energy renovation rate** of residential and non-residential buildings by 2030 and to foster deep energy renovations.
- '**Fit for 55**' Climate Package - EU's **2030 goal** of cutting greenhouse gas emissions at least by **55%** compared to 1990 levels,
- '**REPowerEU**' plan – mid to long term, structural energy efficiency measures as well as smart use of scarce public funding and more **private investments.**



How can the different country characteristics affect the energy-saving pote eff dif

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Modelling the Energy Performance of EU Buildings

DREEM
Dynamic High-Resolution Demand-Side Management Model

Energy demand simulation model

8 EU Countries (Greece, Italy, Spain, Croatia, Romania, Latvia, France and Ireland)

9 Energy Efficiency Measures

Techno-economic analysis to assess the cost-effectiveness on the different measures

Building sector

Energy demand *simulation model*

Benefits *&* ***limitations*** *of demand-flexibility primarily for* ***consumers*** *& other* ***power actors*** *involved*

ELSEVIER

Energy Conversion and Management
Volume 205, 1 February 2020, 112339

A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector

Vassilis Stavrakas, Alexandros Flamos

ELSEVIER

Energy Policy
Volume 161, February 2022, 112759

Monetising behavioural change as a poli measure to support energy management residential sector: A case study in Greece

Konstantinos Koasidis [a], Vangelis Marinakis [a], Alexandros Nikas [a], Katerina Chira [a], Alexa Doukas [a]

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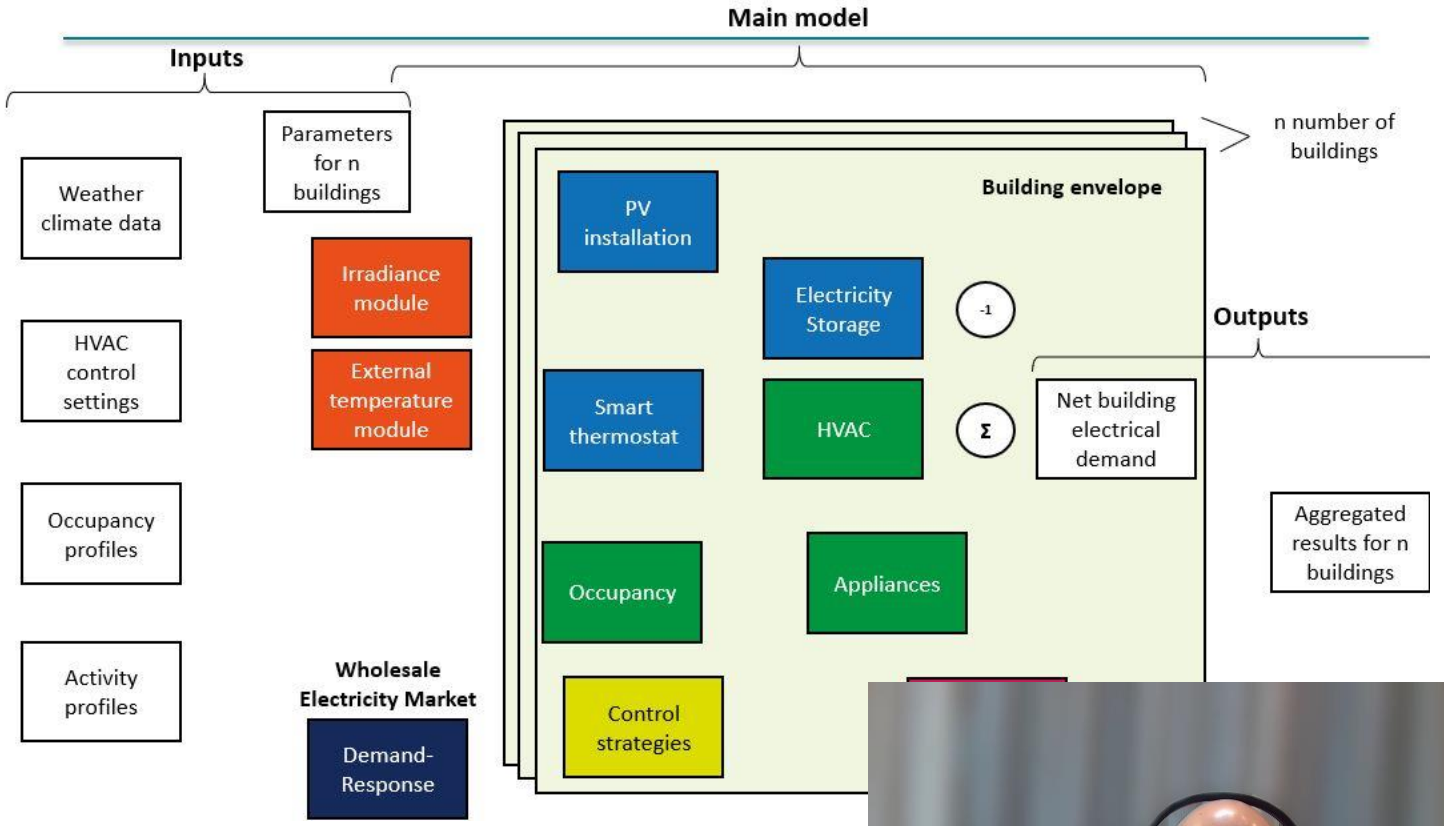
MODEL CHARACTERISTICS (1/2)

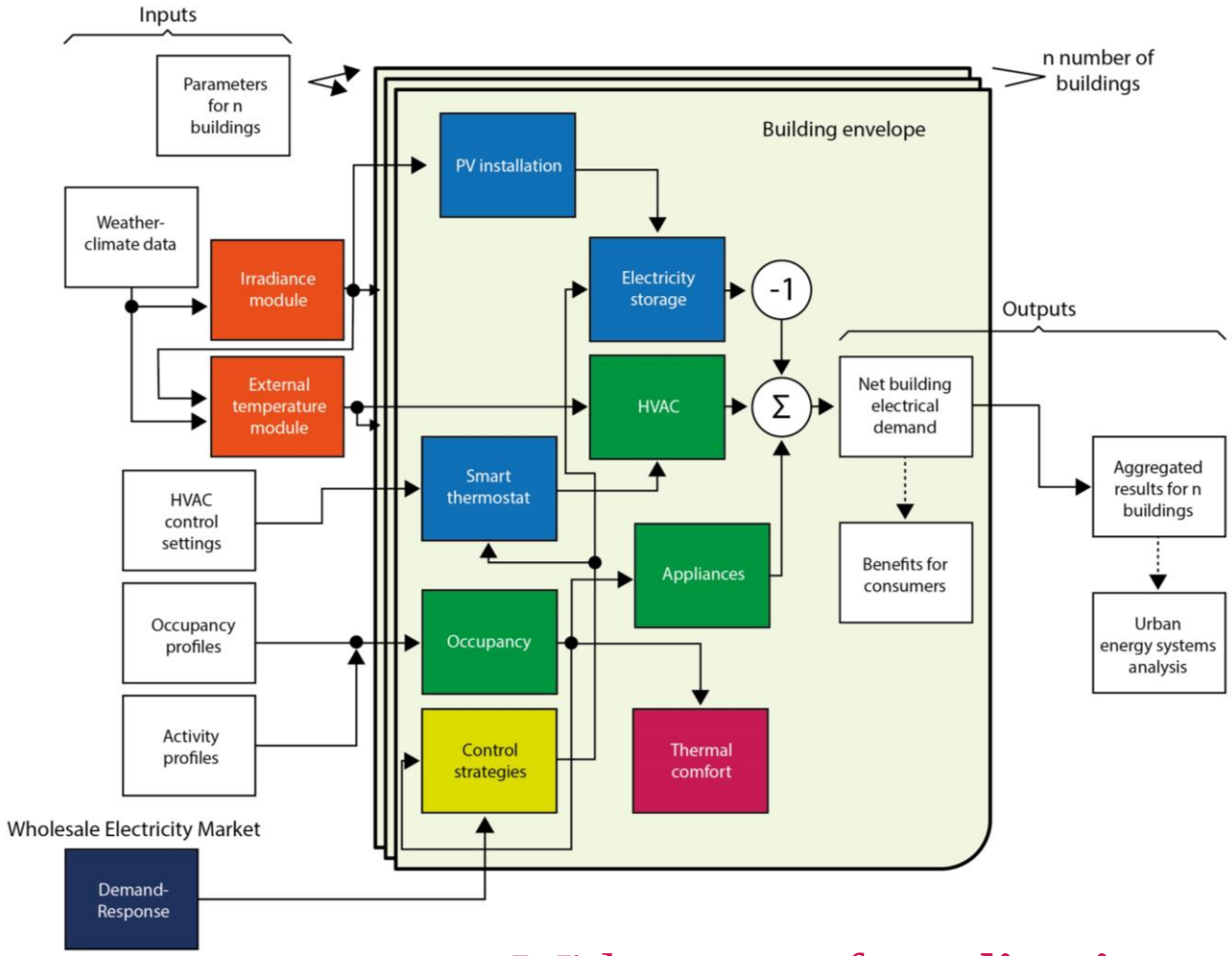
Main **principles** of **component-** & **modular-**based system modeling approach

- **interdependence** of decisions **within** modules
- **independence** of decisions **between** modules
- **hierarchical dependence** of modules on components embodying standards & design rules

Modular *structure*

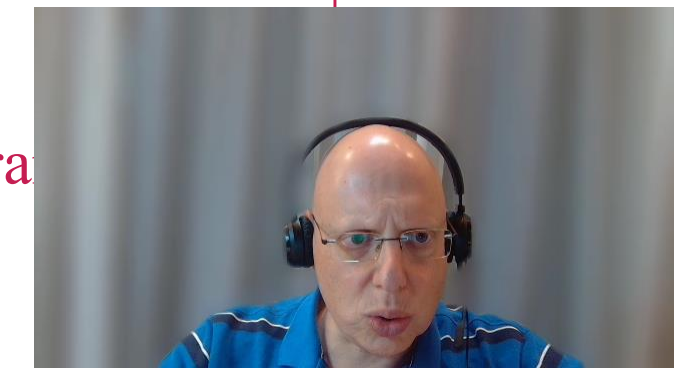


MODEL CHARACTERISTICS (2/2)



- **Incremental** modeling:
  - **sub-models** in multiple levels
- **Control** capabilities: **managing** the **complexity** of large systems
- **Realistic representations** of dynamic systems
- Fast development & simulations: **computational efficiency**

Wide range of **applications** on Europe's energy tra



DATA AND BUILDINGS SPECIFICATIONS

2 categories of buildings based on their construction period

- **Category I:** Buildings that have been built **before 1981*** (the requirement for thermal insulation of buildings was set after 1981)
- **Category II:** Building that have been built in the period **1981-2006**:

Building specifications

TABULA WebTool

Greece, Italy, Spain France & Ireland

ENTRANZE

Croatia, Romania & Latvia

*except for Croatia where the building has been built before 1987

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BUILDING TYPOLOGIES – SOUTH EUROPE (1/2)

Greece

Two reference buildings in the city of **Athens** (Greek Climate Zone B)

<1981 (first class)

1981-2000

Reference Floor Area: 102 m^2

Reference Floor Area: 88 m^2

Italy

Two reference buildings in the city of **Rome** (Italian Climate Zone D)

1961-1975

1990-2005

Reference Floor Area: 156 m^2

Reference Floor

Building Typologies – South Europe (1/2)

Spain

Two reference buildings in the city of **Barcelona**

1960-1979

Reference Floor
Area: 90 m²

1980-2006

Reference Floor
Area: 107 m²

Croatia

Two reference buildings in the city of **Zagreb**

1971-1987

Reference Floor
Area: 96 m²

1988-2005

Reference Floor

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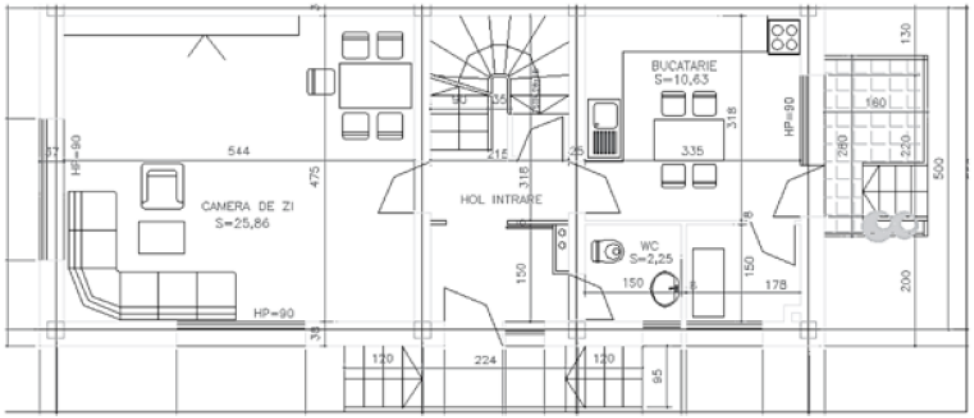
BUILDING TYPOLOGIES - EASTERN EUROPE

Romania

One reference building in the city of **Bucharest**



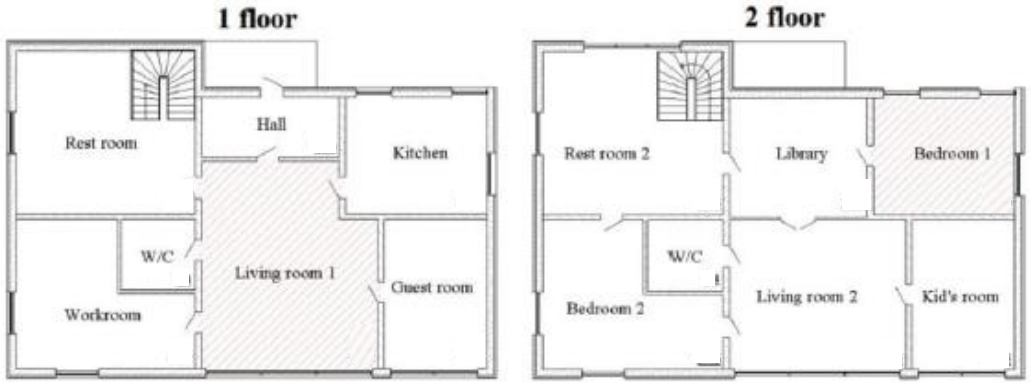
<1979

Reference Floor
Area: 100 m^2

B. Atanasiu *et al.*, "Implementing nearly Zero-Energy Buildings (nZEB) in Romania - Towards a definition and roadmap," *Build. Perform. Inst. Eur.*, 2012.

Latvia

One reference building in the city of **Riga**



1970-1979

Reference Floor
Area: 96

D. Baranova, D. Sovetnikov, and A
extensive analysis of building ene
the Baltic Sea region," Sci. Techn
no. 9, pp. 982–993, 2018.

Building Typologies – Western Europe

France

Two reference buildings in the city of **Paris**

1975-1981

Reference Floor
Area: 97 m²

1990-1999

Reference Floor
Area: 107 m²

Ireland

Two reference buildings in the city of **Dublin**

1975-1981

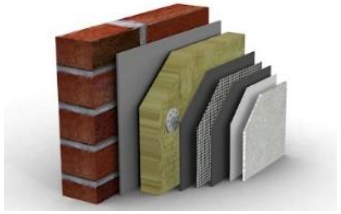
Reference Floor
Area: 125 m²

1990-1999

Reference Floor

ENERGY EFFICIENCY MEASURES (EEMS)

EE Measure 1



Exterior Walls - Improving **insulation** standards of the building envelope

EE Measure 2

Roof Insulation - Thermal retrofit of roofs to reduce the heat load of the buildings under study

EE Measure 3

Windows - Thermal upgrade of windows through double-glazed windows

EE Measure 4

Smart Thermostat- setback states, without compromising thermal comfort of the occupants

EE Measure 5

Replacement of an **oil-fired** boiler with a **modern oil condensing** boiler

EE Measure 6

Replacement of an **oil-fired** boiler with a **natural gas** condensing **boiler**

EE Measure 7

Replacement of an **oil-fired** boiler with a with a **biomass boiler**

EE Measure 8

Replacement of an **o** **fired** boiler with a hi temperature **heat pu**

EE Measure 9

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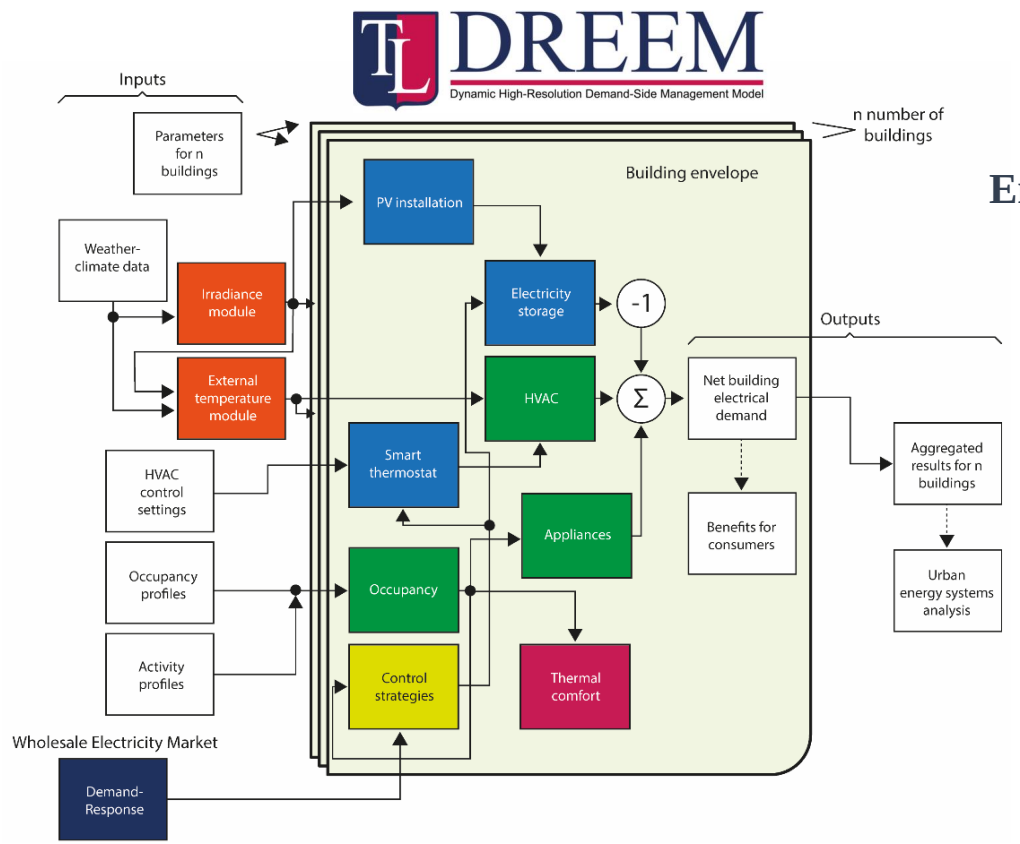
TECHNO-ECONOMIC ANALYSIS

The **Levelised Cost of Saved Energy (LCSE)** is used to assess the **cost effectiveness** of the different EEMs



Energy Savings for each EEM

$$LCSE = \frac{(CRF * \text{Cost}_{investment}) + \text{Cost}_{O\&M}}{Energy\ Svings\ (kWh)}$$

$$Capital\ Recovery\ Factor\ (CRF) = \frac{r * (1+r)^N}{(1+r)^N - 1}$$

where:

- **r:** discount rate
- **N:** lifetime of measures
- **$\text{Cost}_{investment}$:** total in
- **$\text{Cost}_{O\&M}$:** annual operat costs of the energy-savin
- **Energy Savings:** total (kWh/year)

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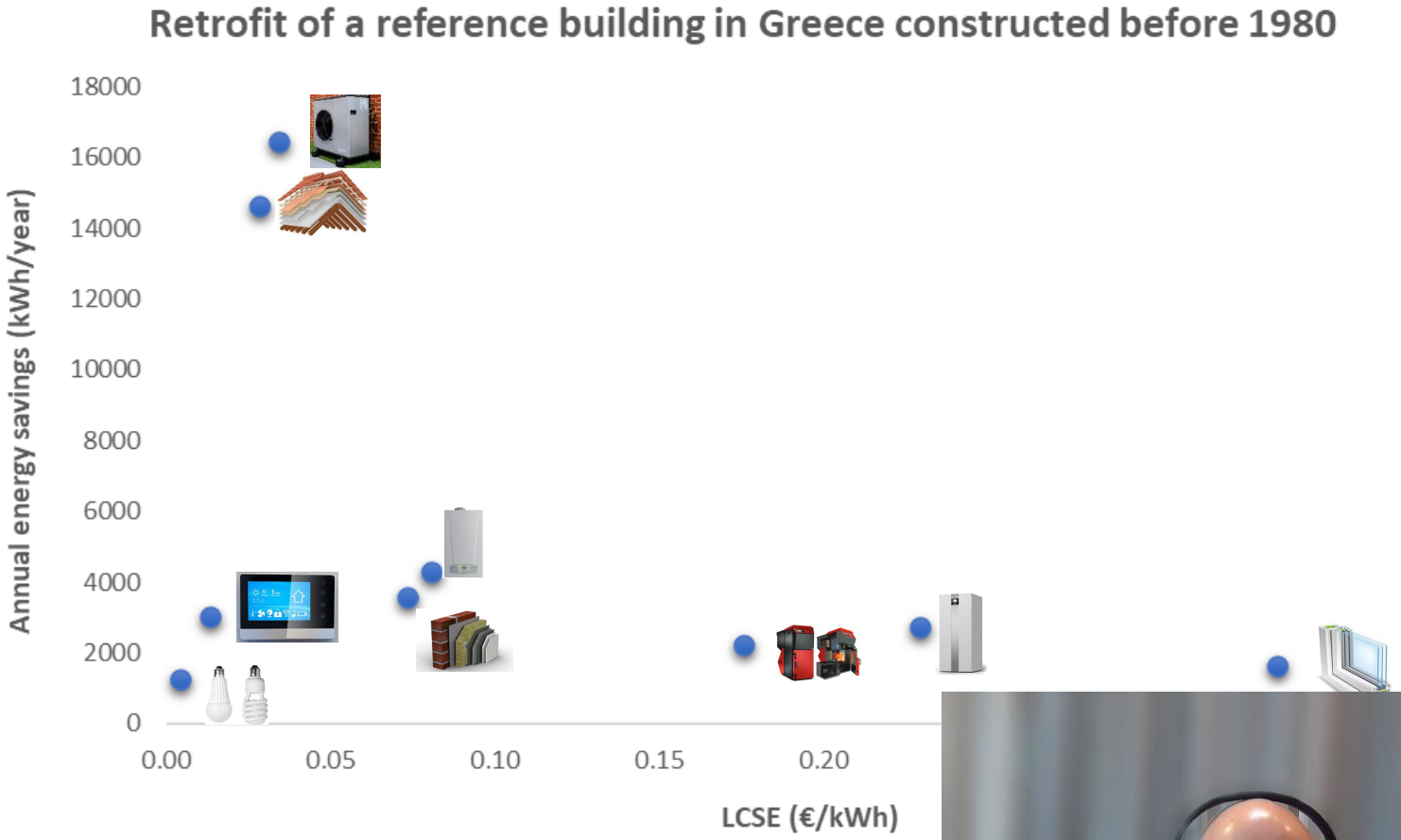
RESULTS (1/14)

Greece (Athens) – Category I

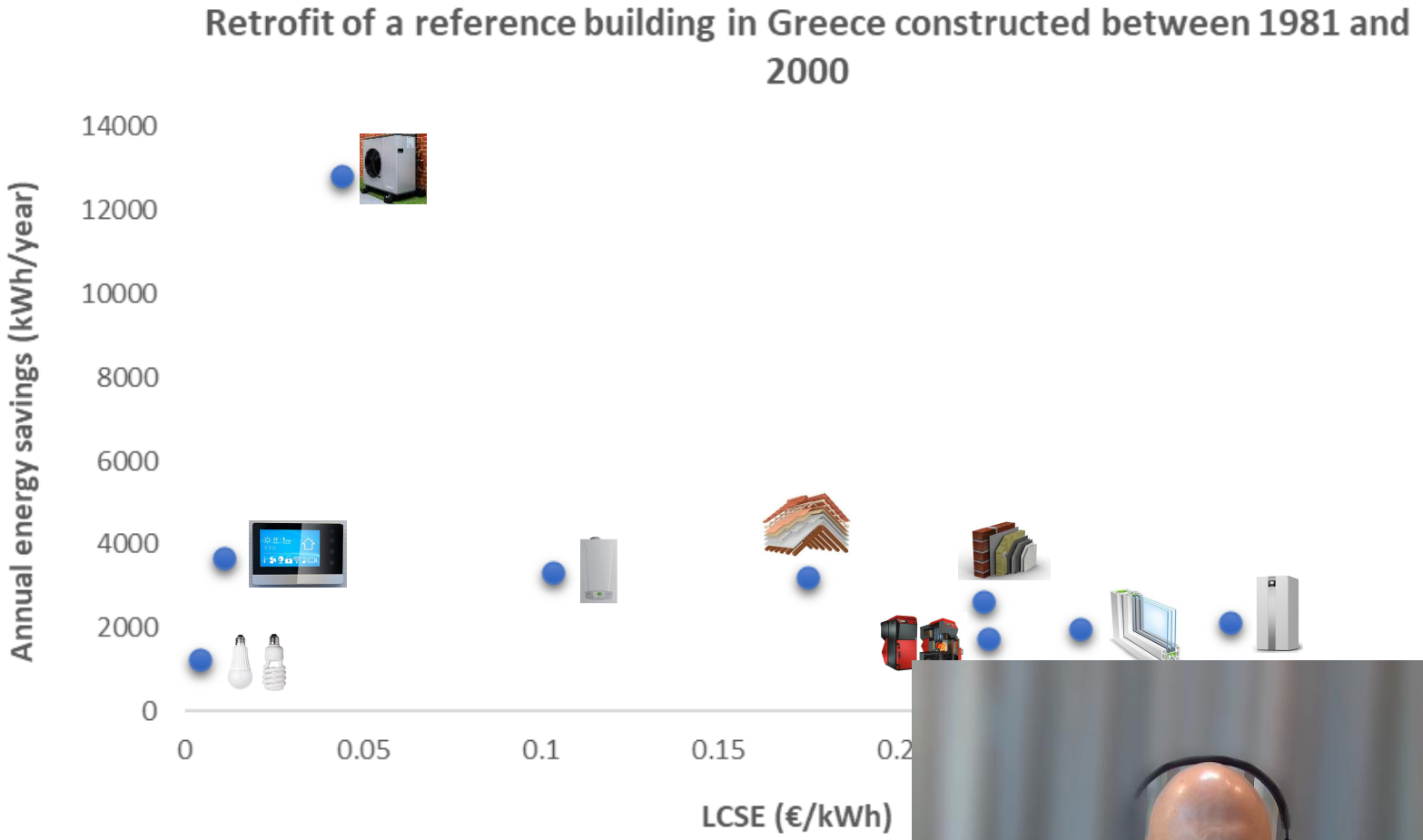
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0732	3586.9
EEM2	0.0283	14626.2
EEM3	**0.3383**	1617.6
EEM4	0.0134	3009.1
EEM5	0.2292	2727.1
EEM6	0.0804	4275.1
EEM7	0.1759	2243.7
EEM8	0.0344	**16435.5**
EEM9	**0.0041**	1245.8



RESULTS (2/14)

Greece (Athens) – Category II

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.2243	2651
EEM2	0.1750	3226
EEM3	0.2515	1987.1
EEM4	0.0109	3680.1
EEM5	**0.2940**	2126.4
EEM6	0.1031	3332.9
EEM7	0.2258	1748.2
EEM8	0.0441	**12813.4**
EEM9	**0.0041**	1247.8



RESULTS (3/14)

Italy (Rome) – Category I

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.2243	2651
EEM2	0.1750	3226
EEM3	0.2515	1987.1
EEM4	0.0109	3680.1
EEM5	**0.2940**	2126.4
EEM6	0.1031	3332.9
EEM7	0.2258	1748.2
EEM8	0.0441	**12813.4**
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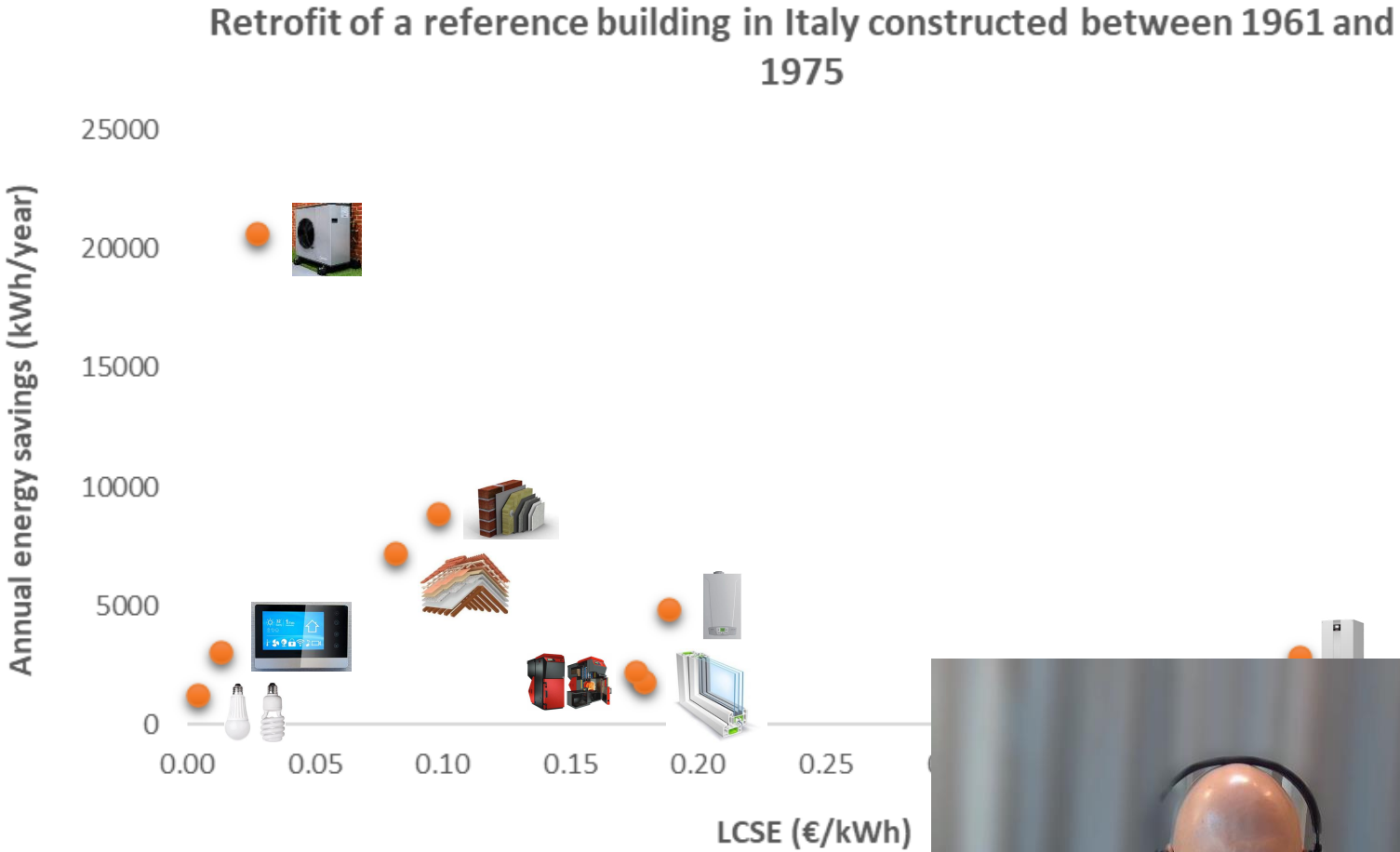
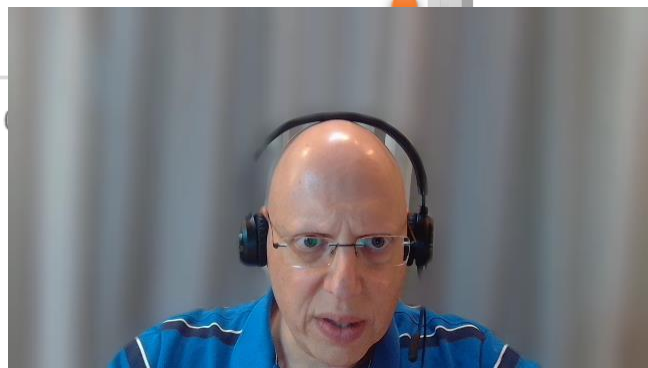
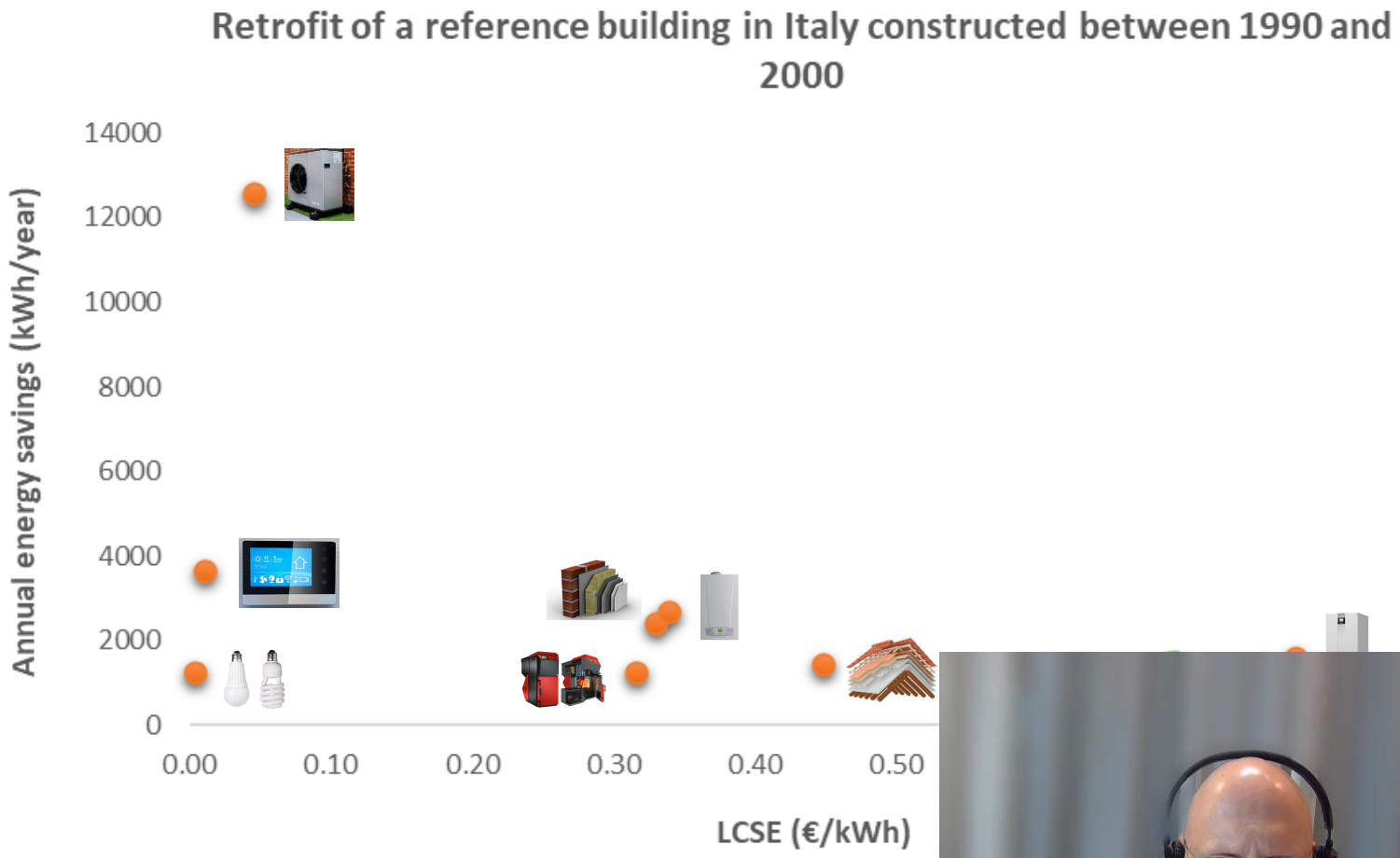




RESULTS (4/14)

Italy (Rome) – Category II

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.3298	2434.8
EEM2	0.4488	1433.7
EEM3	0.6606	540.3
EEM4	0.0110	3644.1
EEM5	**0.7822**	1598.2
EEM6	0.3389	2704.4
EEM7	0.3154	1251.4
EEM8	0.0450	**12570.4**
EEM9	**0.0041**	1245.8



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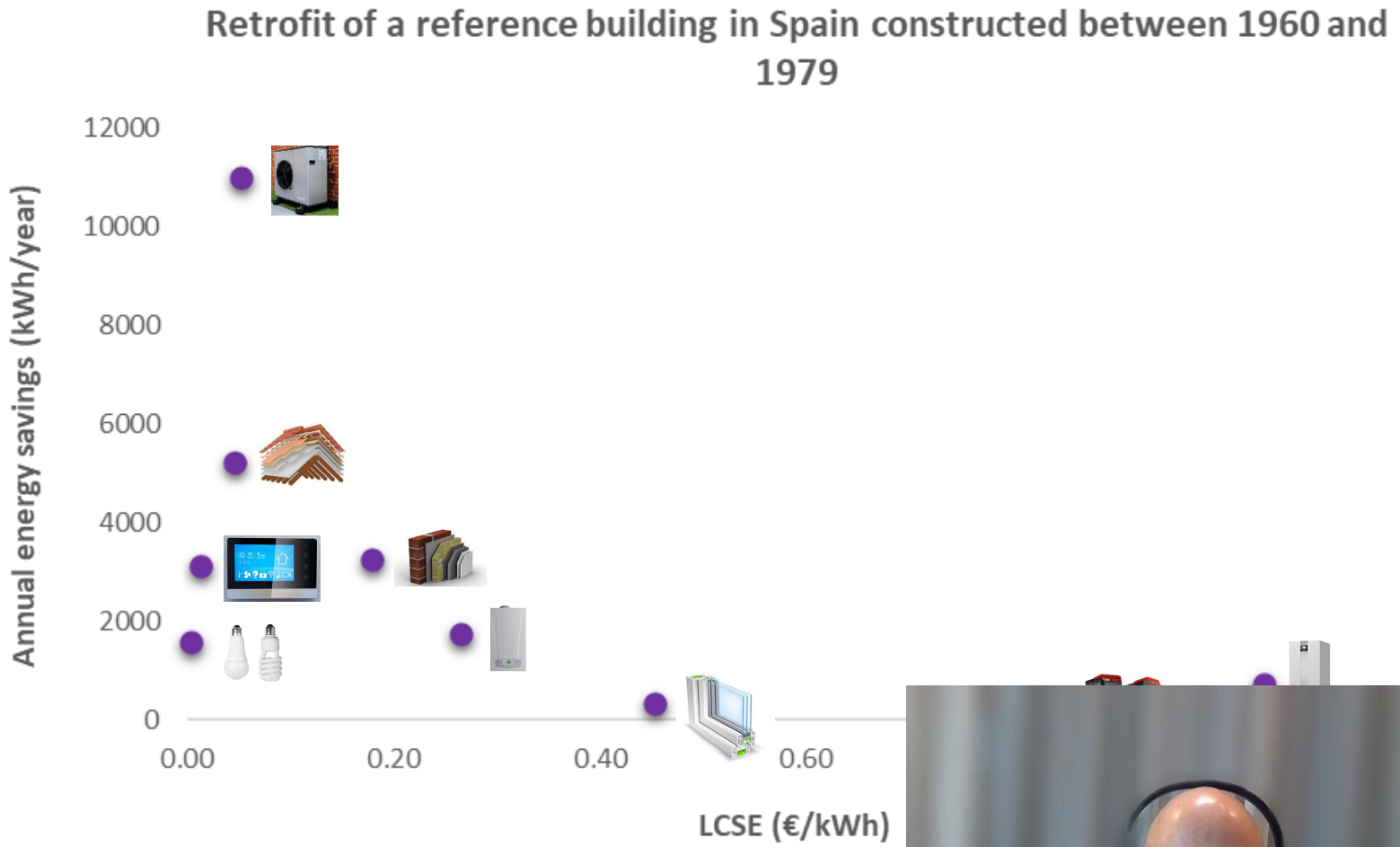
RESULTS (5/14)

Spain (Barcelona) - Category I

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.1791	3243.9
EEM2	0.0461	5226.8
EEM3	0.4521	342.1
EEM4	0.0129	3103.1
EEM5	**1.0431**	719.1
EEM6	0.2647	1731.7
EEM7	0.9801	402.7
EEM8	0.0514	**11003.7**
EEM9	**0.0033**	1579.3



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RESULTS (6/14)

Spain (Barcelona) - Category II

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.1791	3243.9
EEM2	0.0461	5226.8
EEM3	0.4521	342.1
EEM4	0.0129	3103.1
EEM5	**1.0431**	719.1
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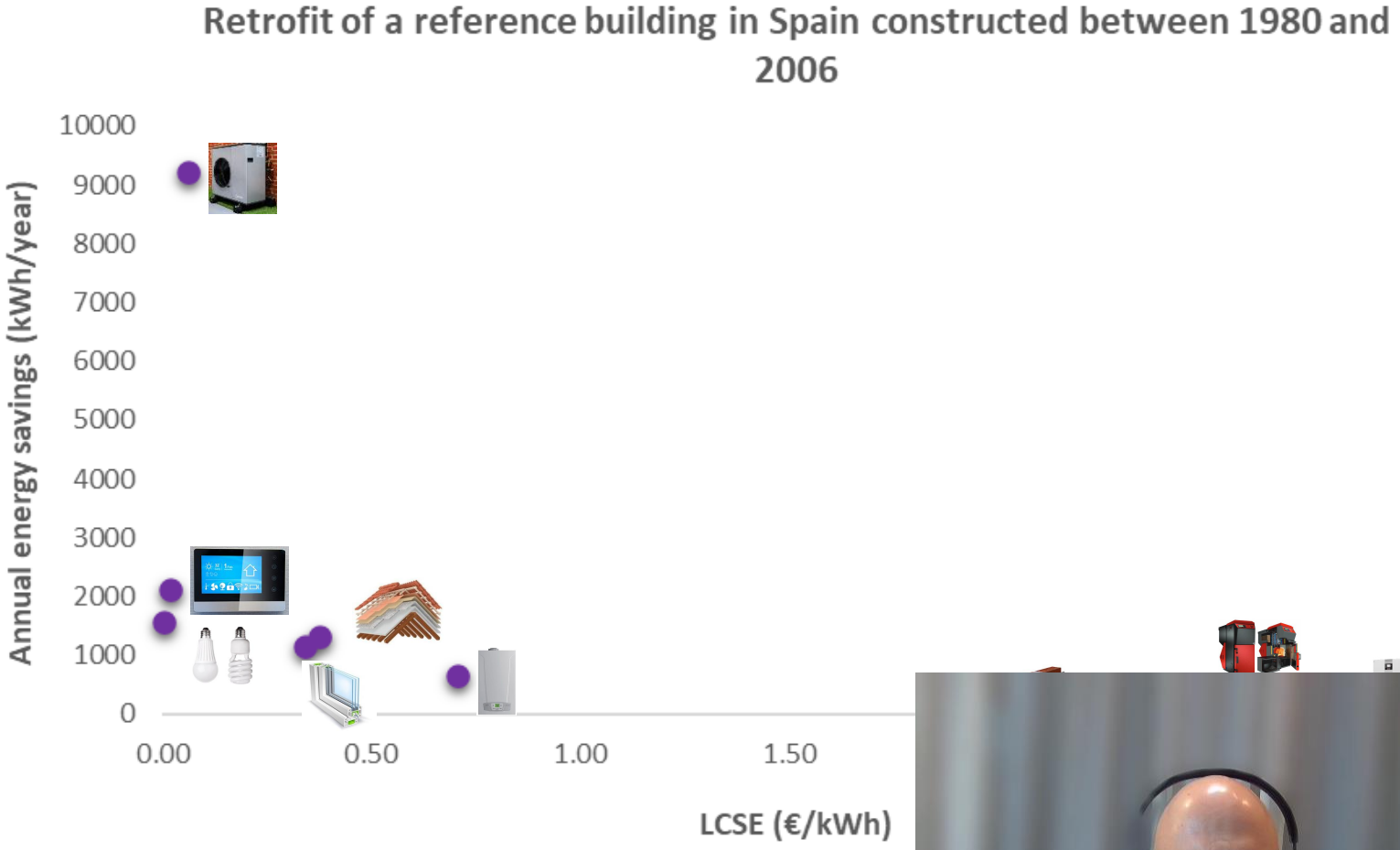
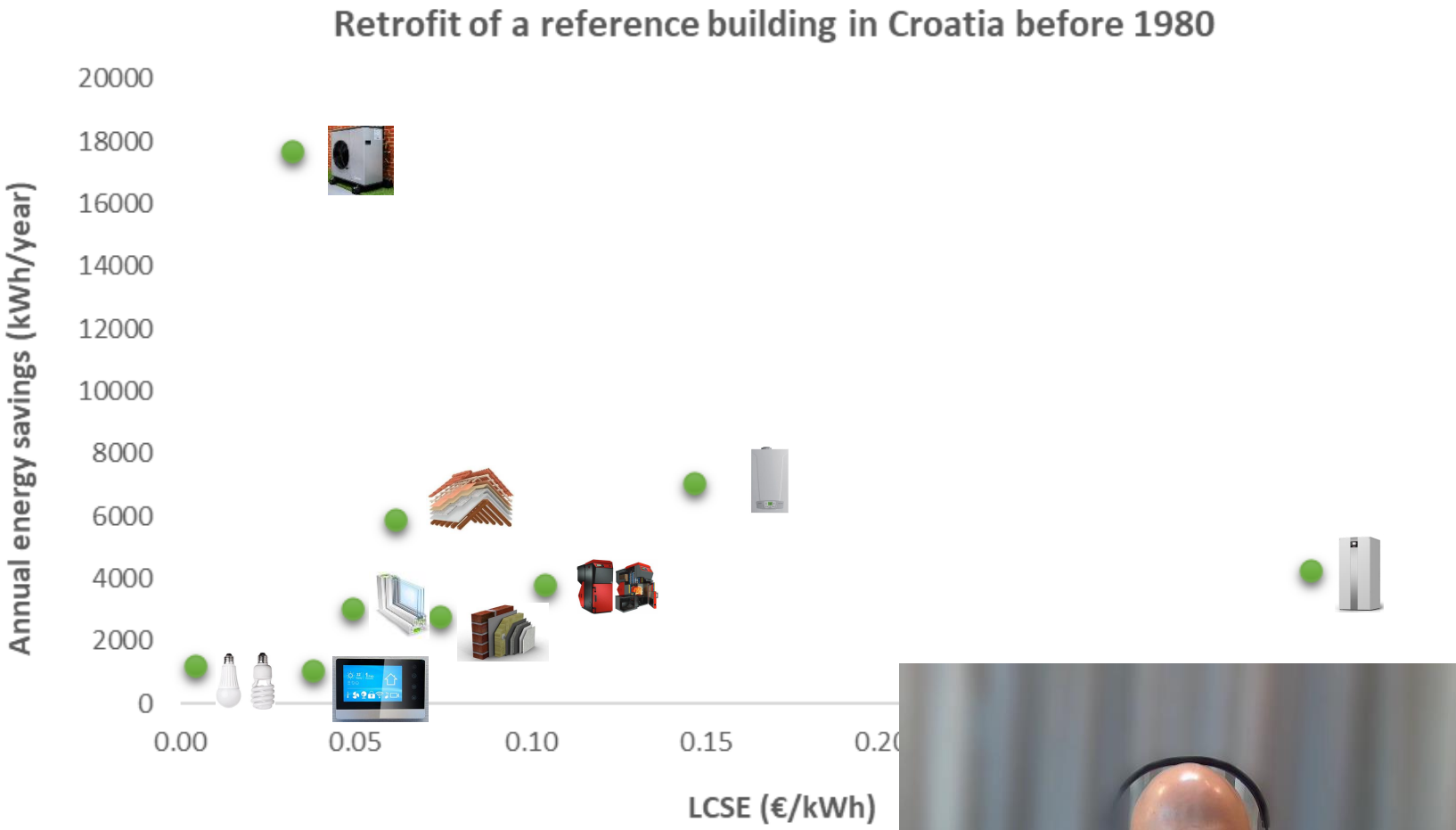


RESULTS (7/14)

Croatia (Zagreb) - Category I

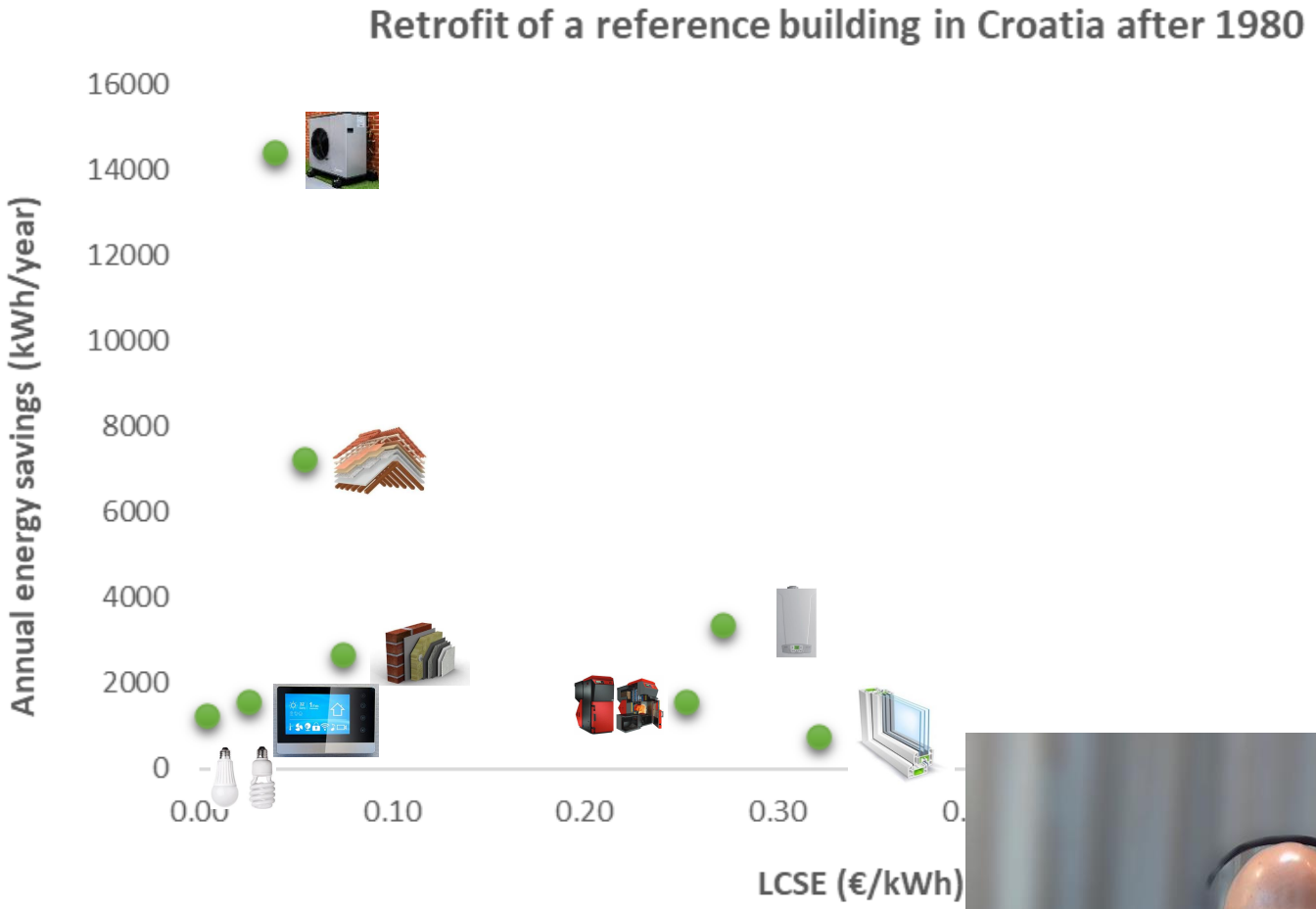
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0740	2771.8
EEM2	0.0612	5917.5
EEM3	0.0489	3035.6
EEM4	0.0376	1068
EEM5	**0.3223**	4267.1
EEM6	0.1463	7048
EEM7	0.1041	3792.9
EEM8	0.0320	**17673.1**
EEM9	**0.0041**	1242.3



RESULTS (8/14)

Croatia (Zagreb) - Category II

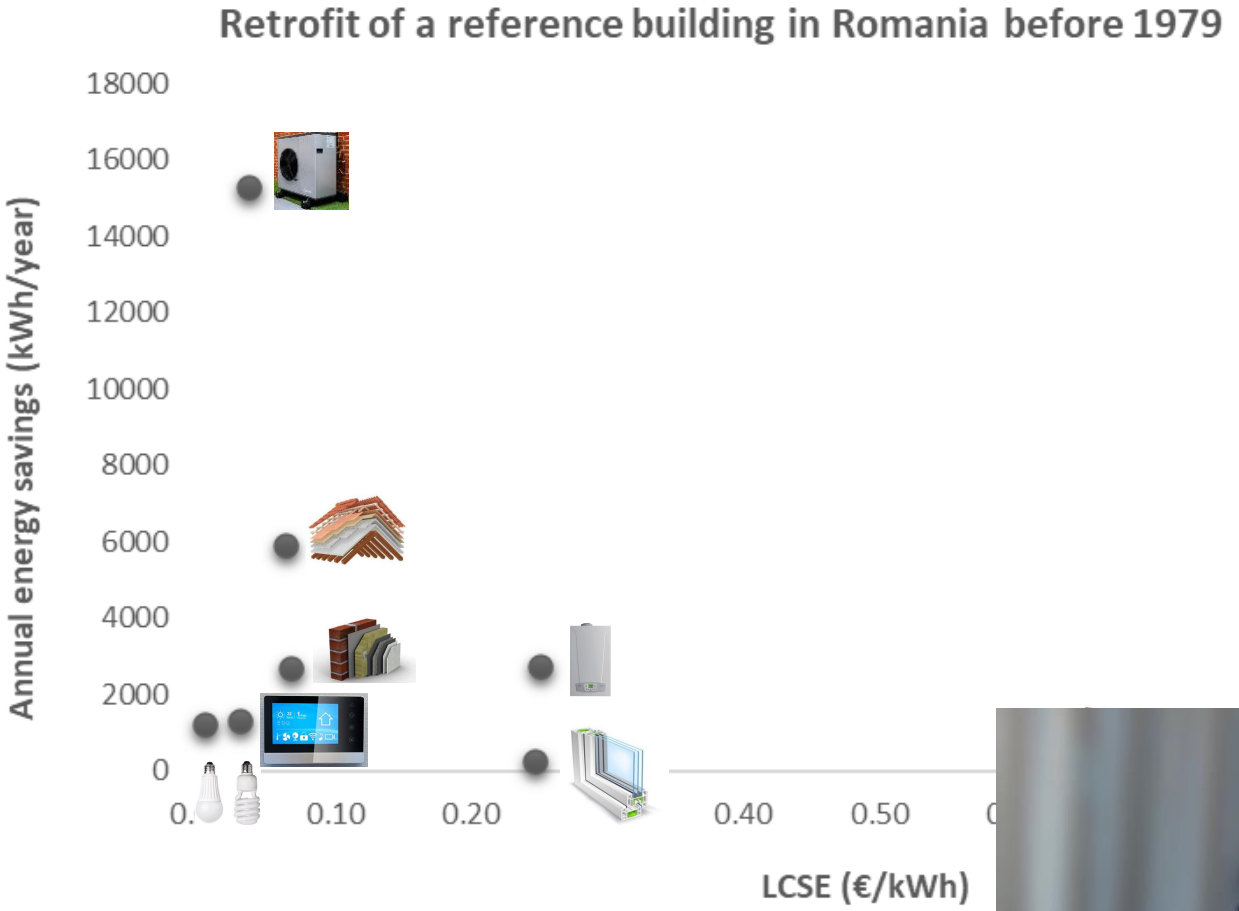
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0746	2680.2
EEM2	0.0541	7228.4
EEM3	0.3211	770.6
EEM4	0.0252	1594.4
EEM5	**0.6270**	1993.9
EEM6	0.2716	3374.6
EEM7	0.2528	1561.3
EEM8	0.0392	**14419.6**
EEM9	**0.0041**	1246.3



RESULTS (9/14)

Romania (Bucharest) – Category I

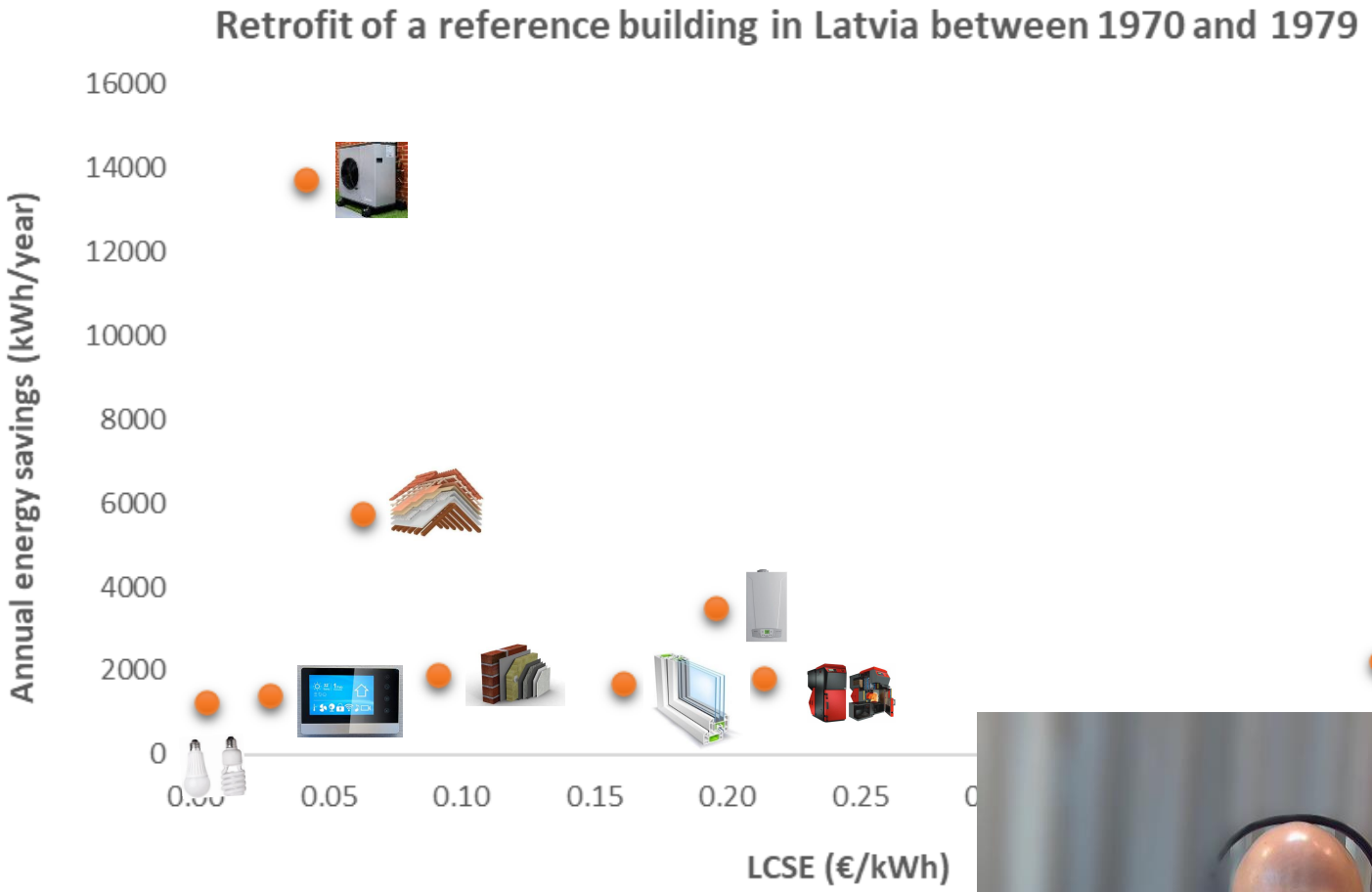
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0675	2688.6
EEM2	0.0631	5948.2
EEM3	0.2470	289.0
EEM4	0.0302	1332.0
EEM5	**0.8758**	1142.0
EEM6	0.2506	2743.4
EEM7	0.6166	640.1
EEM8	0.0369	**15321.1**
EEM9	**0.0041**	1246.0



RESULTS (10/14)

Latvia (Riga) – Category I

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0914	1922
EEM2	0.0627	5765
EEM3	0.1607	1702.9
EEM4	0.0282	1423.1
EEM5	**0.4454**	2245.3
EEM6	0.1954	3518.9
EEM7	0.2138	1845.9
EEM8	0.0412	**13724.1**
EEM9	**0.0041**	1245.7



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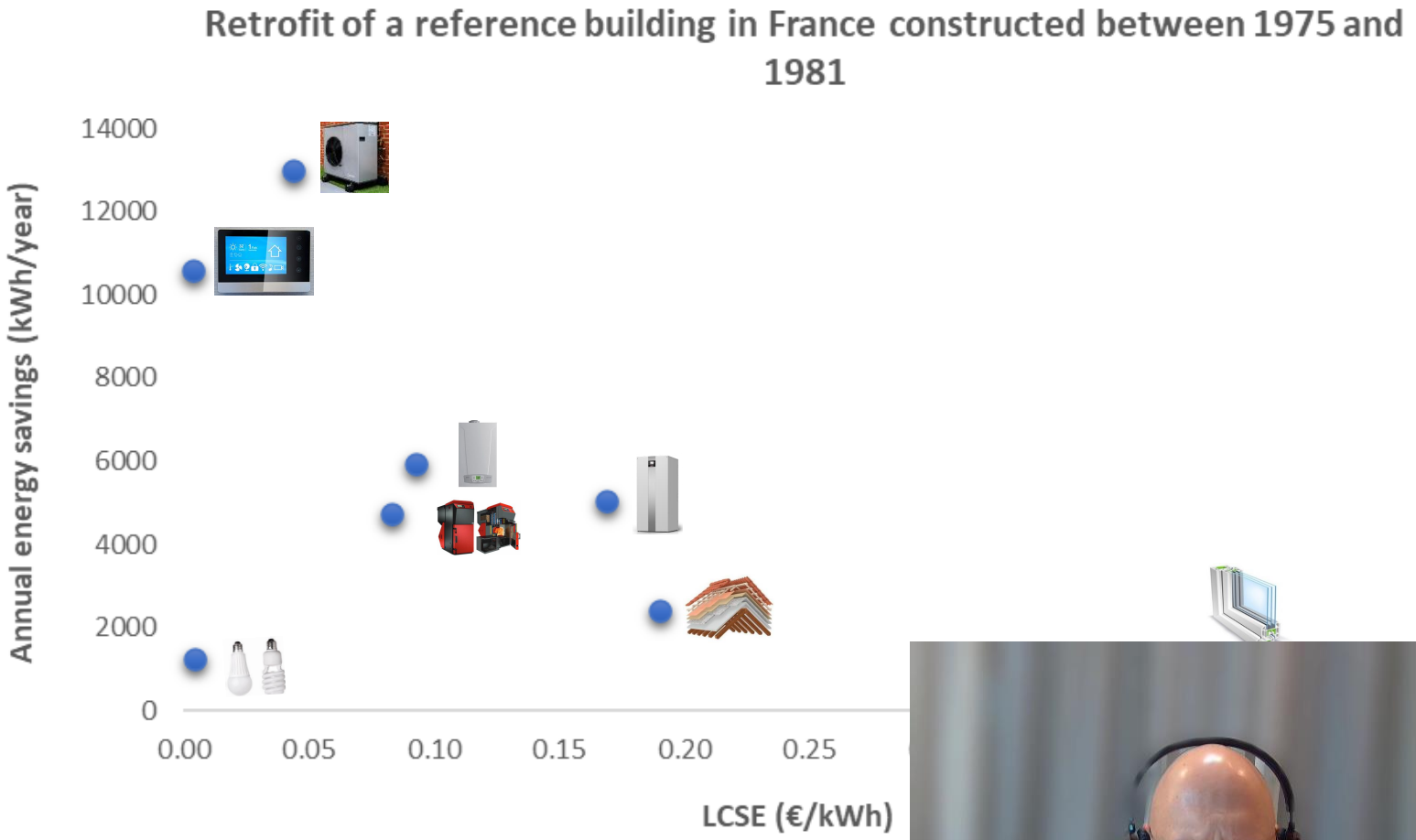
RESULTS (11/14)

France (Paris) – Category I

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.4371	640.4
EEM2	0.1897	2400.2
EEM3	**0.4231**	928
EEM4	0.0038	10593
EEM5	0.1686	5042.7
EEM6	0.0924	5951.6
EEM7	0.0830	4757.9
EEM8	0.0435	**12996.1**
EEM9	**0.0041**	1244.9



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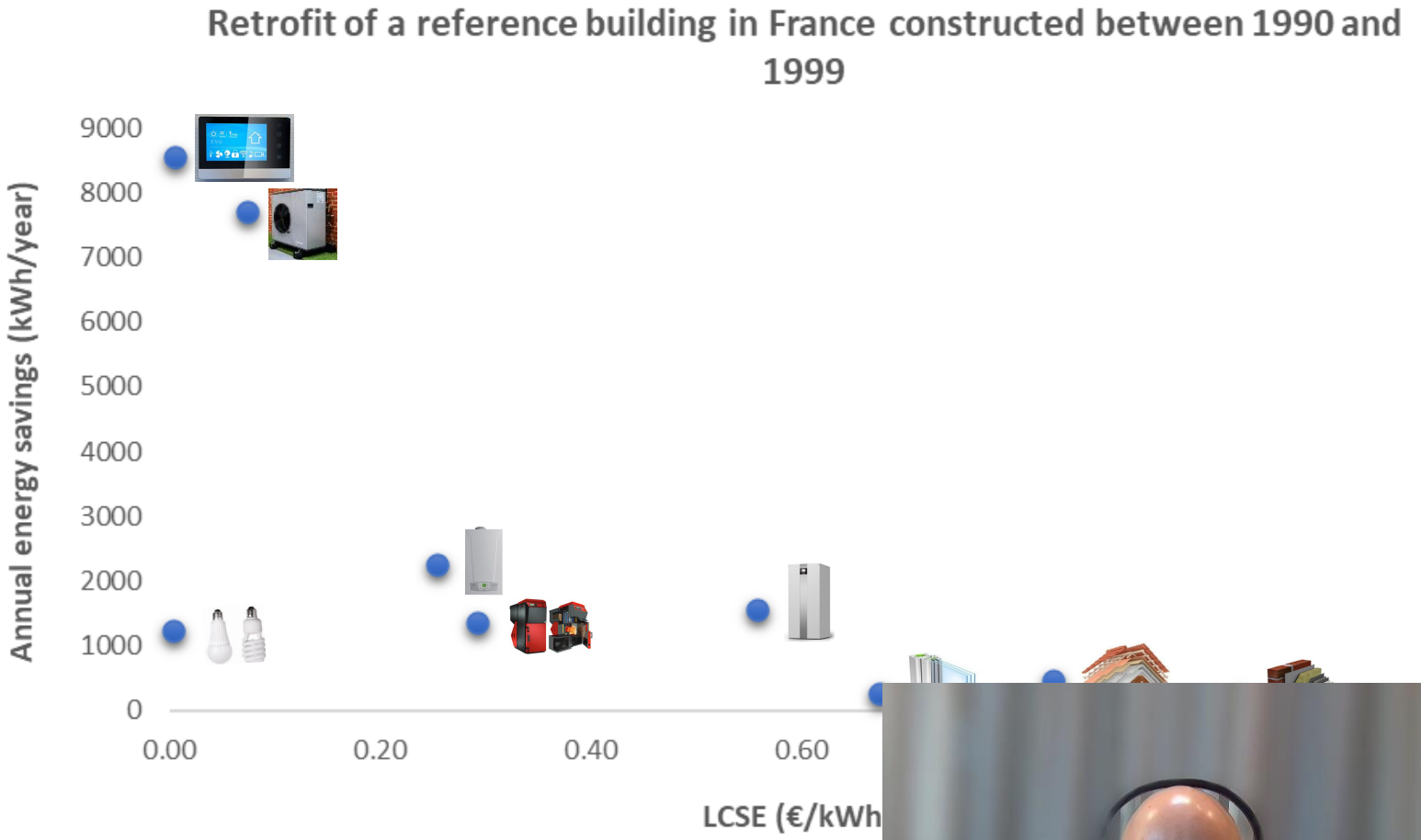
RESULTS (12/14)

France (Paris) – Category II

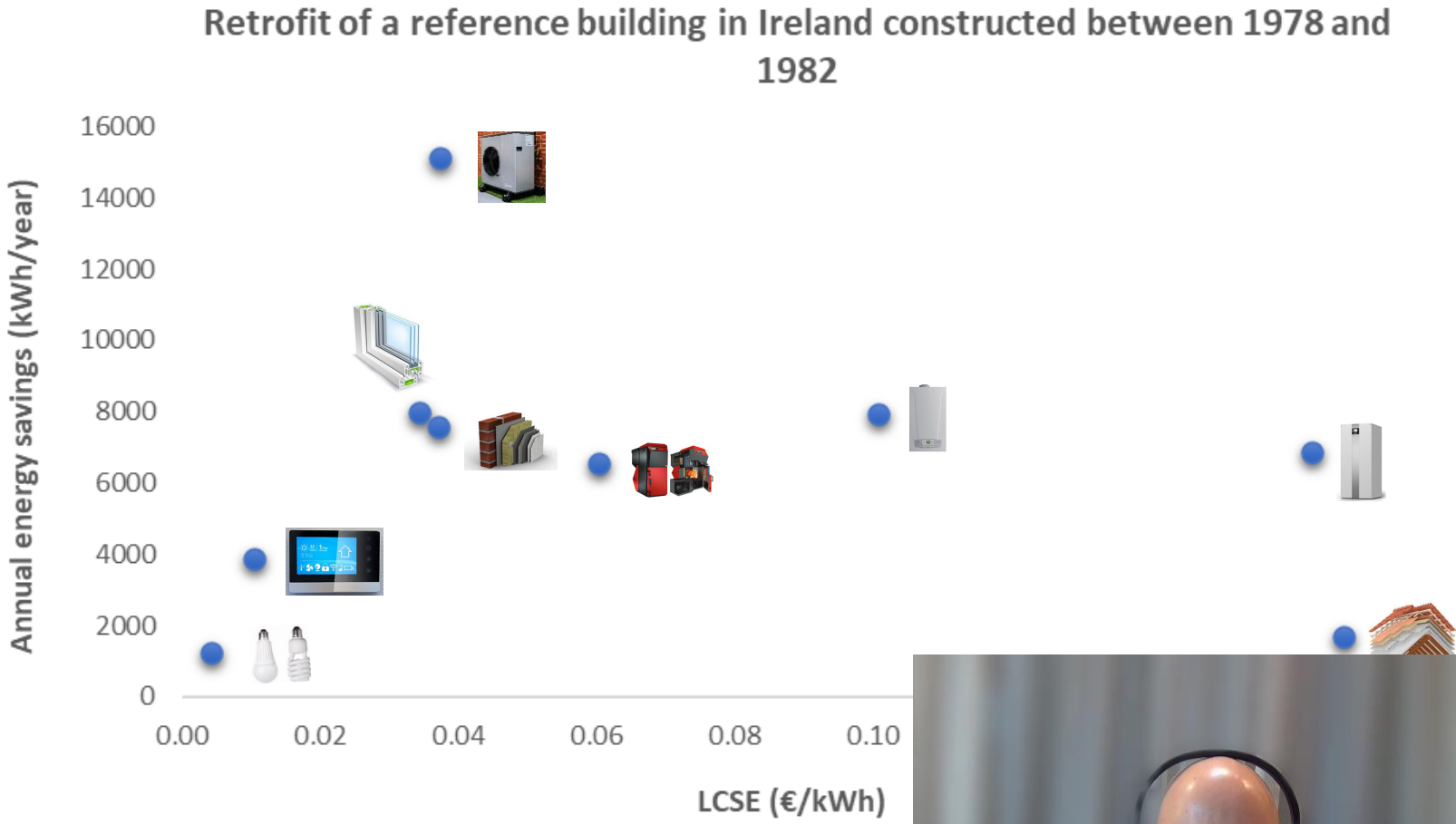
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	**1.0152**	232
EEM2	0.8384	480.3
EEM3	0.6742	264.7
EEM4	0.0047	**8552**
EEM5	0.5570	1571.2
EEM6	0.2531	2263.2
EEM7	0.2914	1354.4
EEM8	0.0734	7701.1
EEM9	**0.0041**	1246.1



RESULTS (13/14)

Ireland (Dublin) – Category I

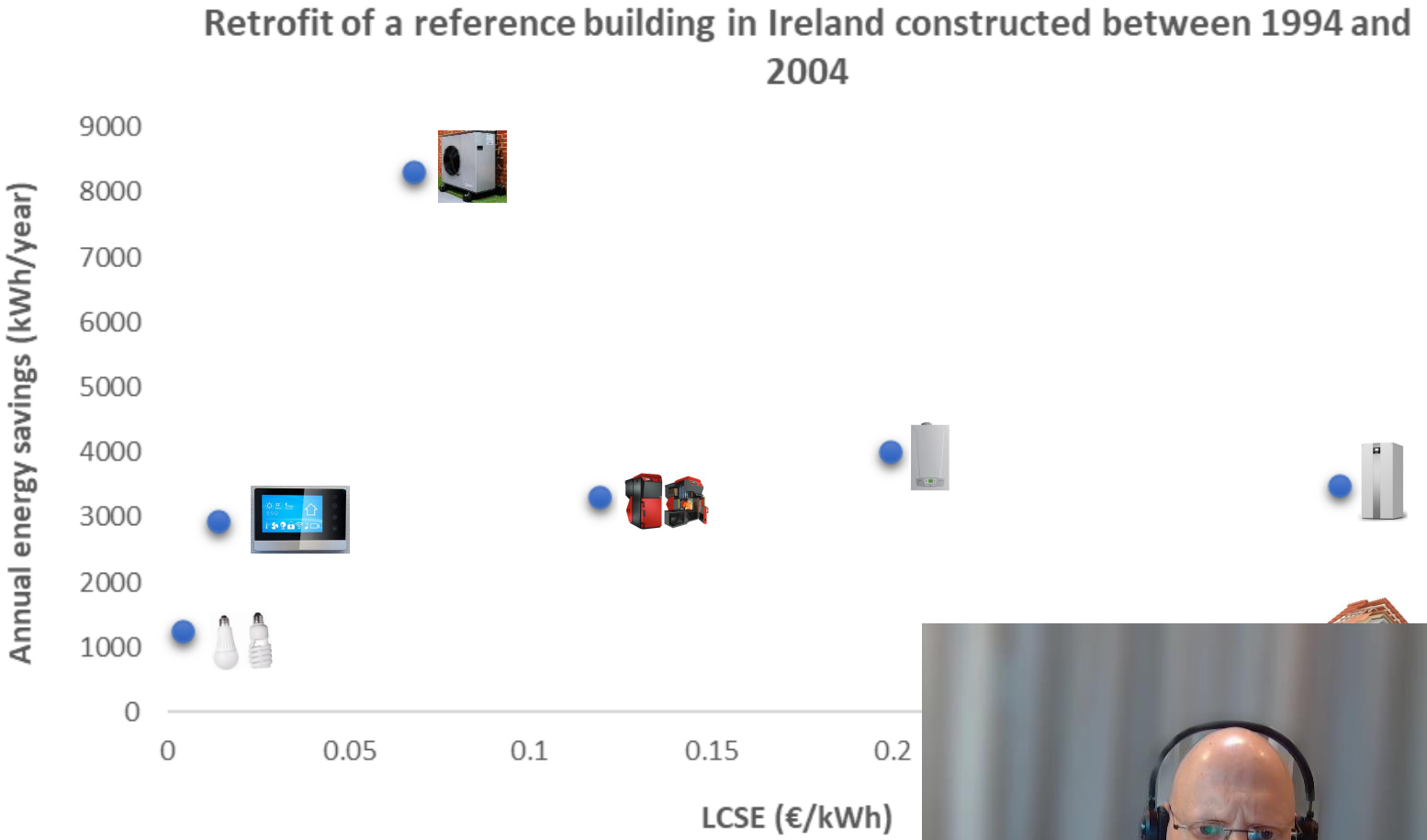
Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0371	7599.9
EEM2	**0.1683**	1699.7
EEM3	0.0342	7992.7
EEM4	0.0104	3867.5
EEM5	0.1637	6872.6
EEM6	0.1009	7945.9
EEM7	0.0604	6536.2
EEM8	0.0374	**15129.5**
EEM9	**0.0041**	1246.1



RESULTS (14/14)

Ireland (Dublin) – Category II

Energy Efficiency Measures	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.3017	479.9
EEM2	0.3101	1043.5
EEM3	0.2625	498.6
EEM4	0.0136	2945.8
EEM5	**0.3231**	3482.6
EEM6	0.1992	4026.3
EEM7	0.1192	3312.3
EEM8	0.0679	**8321**
EEM9	**0.0041**	1246.3



RESULTS – OVERALL (1/3)

- Energy-saving potential of the EEMs is commonly **higher** for buildings in **Category I.**

- The replacement of an old heating system with an **energy-efficient heat pump** system is among the **most cost-effective measures** for all countries, while also illustrates **high energy-saving potential**.

- Replacement of the traditional heating system with a **more energy-efficient diesel boiler** is shown to be the **least cost-effective measure** in most cases.

RESULTS – OVERALL (2/3)

- **Energy-efficient light bulbs** and **smart thermostats** are the most cost-effective measures in both building categories for almost all countries.

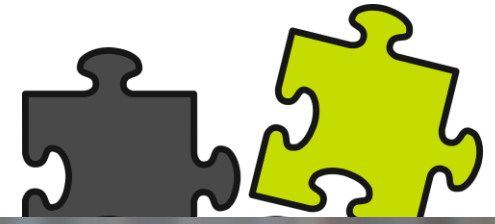
- For the case of Western Europe (France and Ireland) **exterior walls insulation** and **roof insulation** are among the least cost-effective measures, while also **double-glazed windows rank low** in terms of cost-effectiveness in many cases (e.g., France and Greece).

RESULTS – OVERALL (3/3)

- The results of the DREEM model presented in this study can be used to **inform** the development of **financial incentives** for energy-saving actions. Taking into account the **national context**, the study showcases the most and least cost-effective measures per country giving a hint on where the financial resources should be channelled.

- **Scale-up** of DREEM model results can further support policymakers in taking the right pathway that will allow the EU to reach the ambitious **14.5% energy savings goal for 2030***, introduced by the European Parliament this July.

- The DREEM model can also be employed to assess **portfolios of energy efficiency measures** and thus provide valuable information to **one-stop-sho** services.



*Compared to 2020 reference scenario

SUPPORTING EFFORTS AROUND EUROPE TOWARDS OPEN MODELING

DREEM
Dynamic High-Resolution Demand-Side Management Model

scientific reproducibility

public transparency

documentation

datasets

source code

open licenses

SENTINEL
SUSTAINABLE ENERGY TRANSITIONS

publicly available through existing channels

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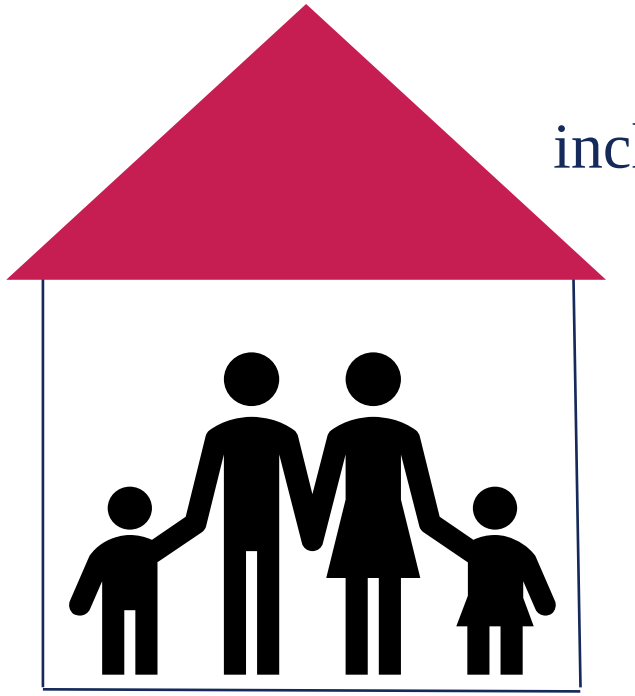
FURTHER RESEARCH

Evaluate the **performance** of **conventional** & **smart EEMs**

- energy savings
- return of investment

Energy poverty



inclusion of **socioeconomic** & **demographic** factors

ENPOR

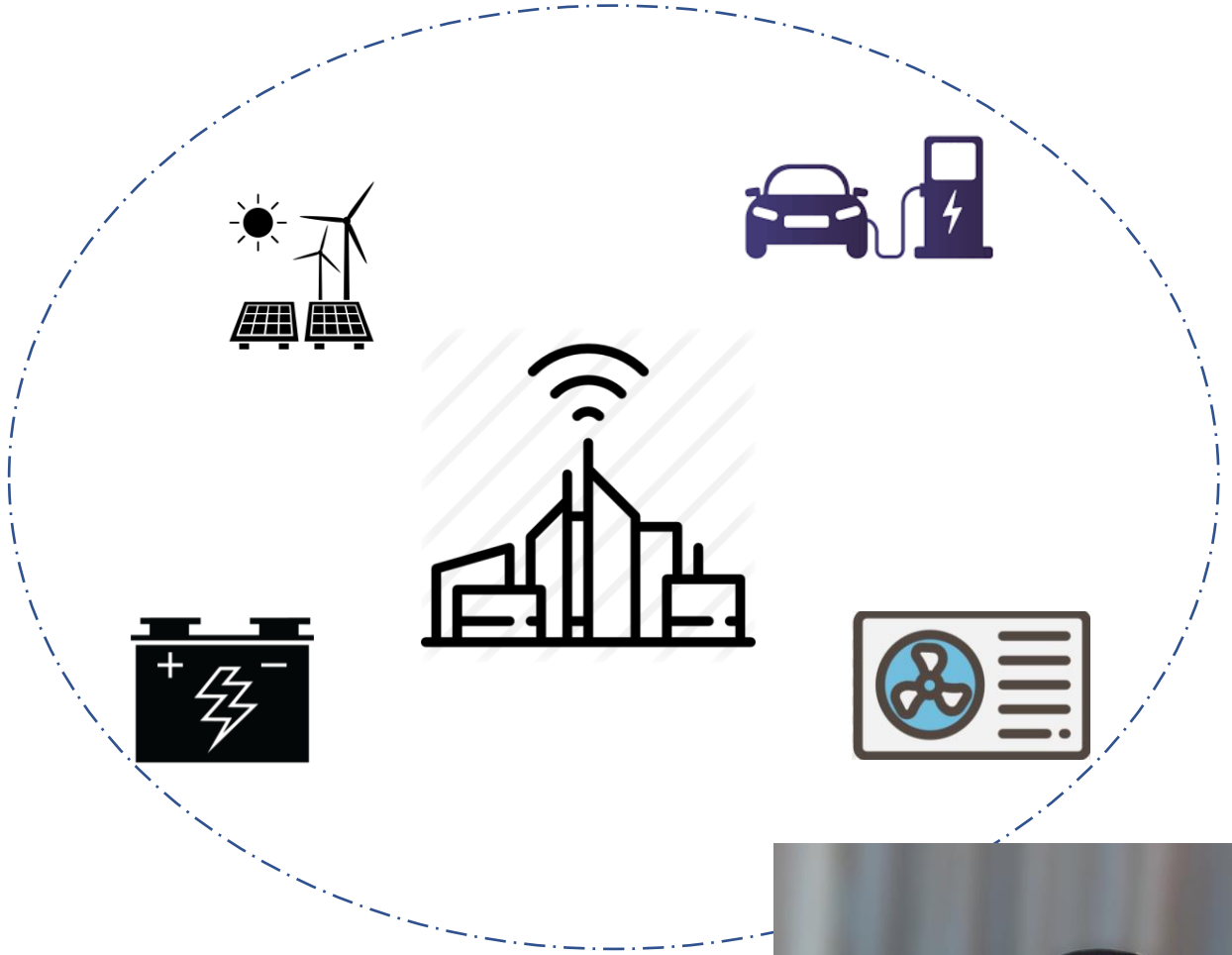
customer profiles

particularities of energy poor households

selection of **tailor-made** EEMs

maximum **impact**

FURTHER RESEARCH



Grid-Interactive-Buildings

FOR MORE INFORMATION…

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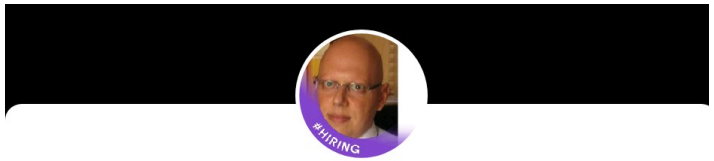

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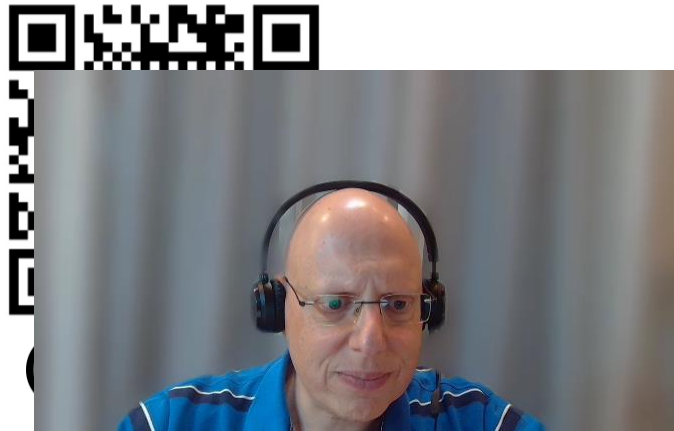

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Thank you for your attention!

ANNEX –ANNUAL SAVINGS & LCSE (1/2)

Category I

	Greece		Italy		Spain		Croatia		Romania		Latvia		France		Ireland	
Energy Efficiency Measures explored	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.0732	3586.9	0.0981	8871.5	0.1791	3243.9	0.0740	2771.8	0.0675	2688.6	0.0914	1922	0.4371	640.4	0.0371	7599.9
EEM2	0.0283	14626.2	0.0811	7241.1	0.0461	5226.8	0.0612	5917.5	0.0631	5948.2	0.0627	5765	0.1897	2400.2	**0.1683**	1699.7
EEM3	**0.3383**	1617.6	0.1788	1863.6	0.4521	342.1	0.0489	3035.6	0.2470	289.0	0.1607	1702.9	**0.4231**	928	0.0342	7992.7
EEM4	0.0134	3009.1	0.0132	3042.9	0.0129	3103.1	0.0376	1068	0.0302	1332.0	0.0282	1423.1	0.0038	10593	0.0104	3867.5
EEM5	0.2292	2727.1	**0.4352**	2872.9	**1.0431**	719.1	**0.3223**	4267.1	**0.8758**	1142.0	**0.4454**	2245.3	0.1686	5042.7	0.1637	6872.6
EEM6	0.0804	4275.1	0.1885	4863.1	0.2647	1731.7	0.1463	7048	0.2506	2743.4	0.1954	3518.9	0.0924	5951.6	0.1009	7945.9
EEM7	0.1759	2243.7	0.1754	2250.2	0.9801	402.7	0.1041	3792.9	0.6166	640.1	0.2138	1845.9	0.0830	4757.9	0.0604	6536.2
EEM8	0.0344	**16435.5**	0.0273	**20678.9**	0.0514	**11003.7**	0.0320	**17673.1**	0.0369	**15321.1**	0.0412	**13724.1**	0.0435	**12996.1**	0.0374	**15129.5**
EEM9	**0.0041**	1245.8	**0.0041**	1246	**0.0033**	1579.3	**0.0041**	1242.3	**0.0041**	1246.0	**0.0041**	1245.7	**0.0041**	1244.9	**0.0041**	1246.1

ANNEX –ANNUAL SAVINGS & LCSE (2/2)

Category II

	Greece		Italy		Spain		Croatia		France		Ireland	
Energy Efficiency Measures explored	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)	LCSE (€/kWh)	Annual energy savings (kWh/year)
EEM1	0.2243	2651	0.3298	2434.8	0.1791	3243.9	0.0746	2680.2	**1.0152**	232	0.3017	479.9
EEM2	0.1750	3226	0.4488	1433.7	0.0461	5226.8	0.0541	7228.4	0.8384	480.3	0.3101	1043.5
EEM3	0.2515	1987.1	0.6606	540.3	0.4521	342.1	0.3211	770.6	0.6742	264.7	0.2625	498.6
EEM4	0.0109	3680.1	0.0110	3644.1	0.0129	3103.1	0.0252	1594.4	0.0047	**8552**	0.0136	2945.8
EEM5	**0.2940**	2126.4	**0.7822**	1598.2	**1.0431**	719.1	**0.6270**	1993.9	0.5570	1571.2	**0.3231**	3482.6
EEM6	0.1031	3332.9	0.3389	2704.4	0.2647	1731.7	0.2716	3374.6	0.2531	2263.2	0.1992	4026.3
EEM7	0.2258	1748.2	0.3154	1251.4	0.9801	402.7	0.2528	1561.3	0.2914	1354.4	0.1192	3312.3
EEM8	0.0441	**12813.4**	0.0450	**12570.4**	0.0514	**11003.7**	0.0392	**14419.6**	0.0734	7701.1	0.0679	**8321**
EEM9	**0.0041**	1247.8	**0.0041**	1245.8	**0.0033**	1579.3	**0.0041**	1246.3	**0.0041**	1246.1	**0.0041**	1246.3