Estimation of Embodied CO_2 in Electro-Mechanical Installations for an Urban Hellenic Dwelling

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OUTLINE OF THE PRESENTATION

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- MOTIVATION
- CASE STUDY - AIM
- METHODOLOGY
- RESULTS AND DISCUSSION
- CONCLUSIONS
- FUTURE RESEARCH

INTRODUCTION

- **Total Energy = Operational Energy + Embodied Energy**
- **Operational Energy (OE)**: the amount of energy that is consumed by a building to satisfy the demand for heating, cooling, ventilation, lighting, equipment and appliances.
- **Embodied Energy (EE)**: the energy consumed to extract, process, manufacture, transport & delivery building construction materials & equipment components.
- **Embodied CO2 (ECO2)**: the quantity of carbon (CO2) emitted into the atmosphere, corresponding to the consumed EE.
- **Net Zero Energy Building (NZEB)**: a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site (European Parliament).
- **Life Cycle Zero Energy Building (LC-ZEB):** A building where the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems, including energy generating ones, over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building over their lifetime **[1]**.

[1] *P. Hernandez and P. Kenny, "From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB)", Energy and Buildings, Vol. 42, 6, pp. 815–821.*

MOTIVATION

•The building sector is responsible for about the 40% of energy consumption in Europe.

• While in usual buildings EE was a small portion of the total energy in the context of lifecycle analysis, moving towards NZEB and LC-ZEB, EE becomes important in the overall energy balance of the building.

• To account for the EE of a building, constitutive materials of the building components and their quantities have to be determined, as well as the database of EE coefficients for these materials should be known. However, EE coefficients are nationally dependent and there is neither Greek EE database nor studies quantifying the average material quantities used in Greek buildings.

• Information about the dominant materials would be valuable to prioritize national needs for developing EE databases, to be used for a global assessment of the EE for the existing building stock and for the life cycle assessment of new buildings.

CASE STUDY - AIM

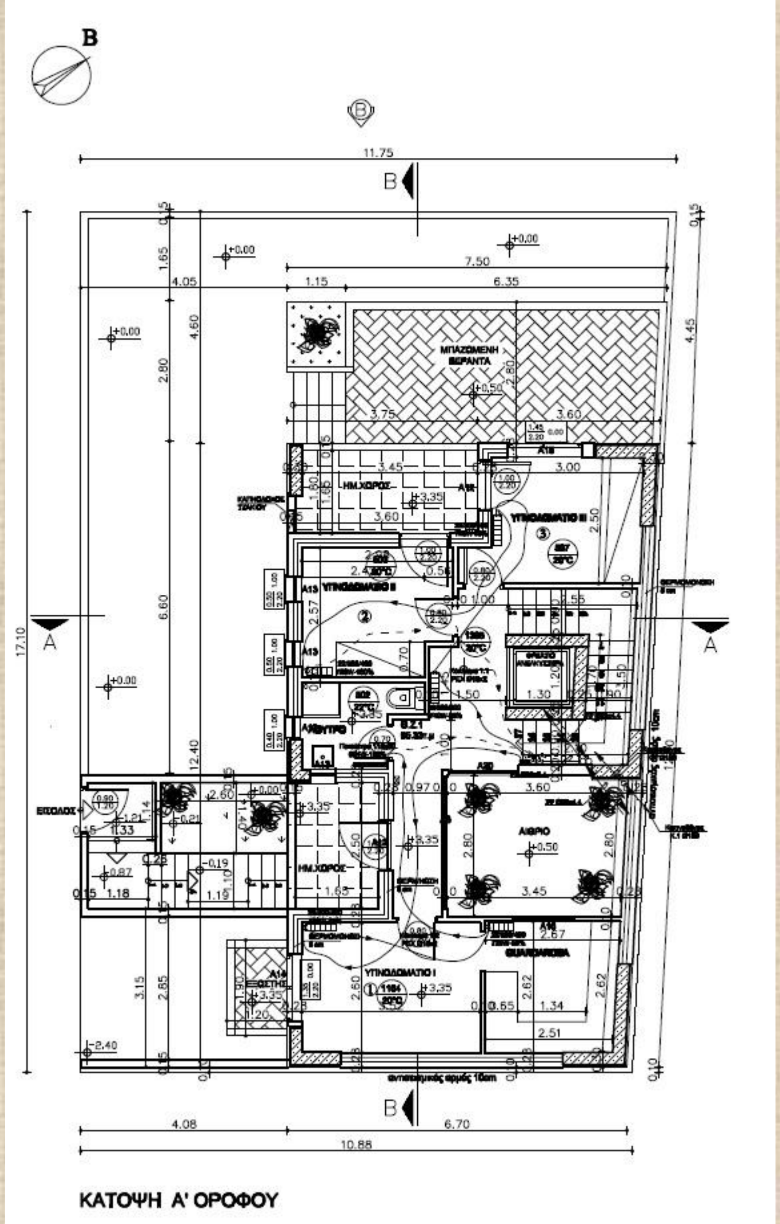
- Among the different **climatic zones** in Greece (A, B, C, D), **building typologies** (urban, single- or multi-family, etc) and **construction dates** (<1980)(1980-2000)(2000-2010)(KENAK), a typical urban two-story (mezonette , 152m2) single-family dwelling was selected, located in Athens.

- A breakdown methodology to derive the main constitutive materials of Electromechanical (E/M) installations and corresponding EE and ECO2 values is presented and implemented for the building of the case study, extending previous similar work **[2]** (three-floor multi-family apartment building).

- The results are compared in terms of repeatability and possible correlations between the two cases. The contribution of E/M installations to the building's environmental footprint is assessed.

- Such results concerning EE and ECO_2 may be taken into account in the context of the ongoing national efforts to implement various energy conservation measures in existing buildings.

[2] *D.G. Koubogiannis, A. Daskalaki and C.A. Balaras, "A contribution to Building Lifecycle Analysis: Embodied energy analysis of mechanical installations for a typical urban Greek dwelling", 3rd International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS3), 07 -09 July, 2013, Nisyros – Greece.*



METHODOLOGY

Main E/M installations = 4 distinct groups of major components:

- **Space Heating (SH)** (boiler, oil burner, fuel tank, flue gas exhaust, pump, radiators, pipe network, expansion tank, valves and other components like magnesium anode, thermostats, deaerators, etc).
- **Hot Water (HW)** (solar collectors, hot water storage tank, support base, various fittings and accessories, hot water pipe network).
- **Air Conditioning (AC)** (split unit heat pumps, i.e. internal units (vaporizer, fan, motor, support materials) and external units (condenser, compressor, fan, motor, four-way valve), connection and drainage materials).
- **Electrical (EL)** (panels, cables, pipes and wall plugs (for SH, for HW and for lighting network).

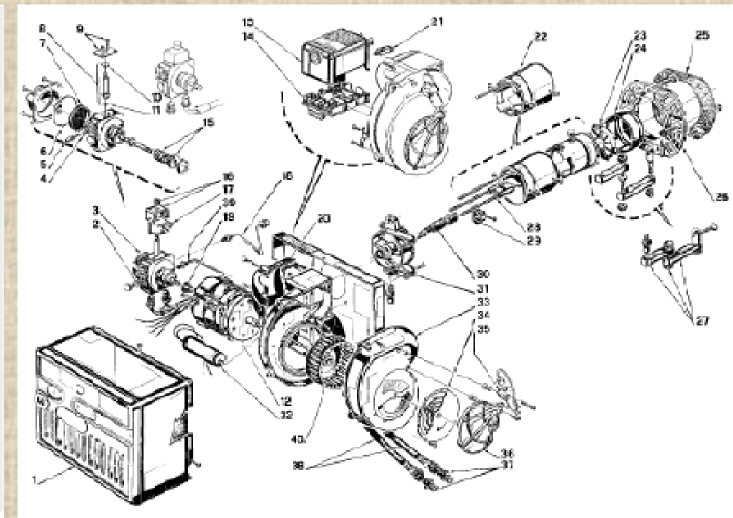
For each major component, the following tasks were carried out:

- (T1) **Item analysis** (breakdown of a **group of major components** to its constitutive **basic items**): This was accomplished by identifying the major items of the group and splitting them continuously to **sub-items** till reaching the level of *basic items*, i.e. the lower level entities in the item tree that cannot be further split into sub-items, but rather to their constitutive **single materials**.
- (T2) **Material analysis** (breakdown of the **basic items** to their constitutive **single materials**): identify and record the **single materials** that make up the **basic items** recorded in (T1).
- (T3) **Mass analysis**: evaluate the mass contribution of each **single material** in the **basic item** it belongs.
- (T4) **EE-ECO_2 analysis**: estimate the EE and ECO_2 contributions of each single material in the whole EM set.

The above procedure can be briefly described by the sequence:

Electro-Mechanical installations *(EM)* → ***groups of major components*** *(SH, HW, AC, EL)* → ***major items*** *(e.g. boiler, radiators, etc)* → ***sub-items*** *(e.g. burner breakdown)* → … → ***basic items*** → ***constitutive single materials*** (steel, iron, copper, aluminum, glass, etc).

METHODOLOGY



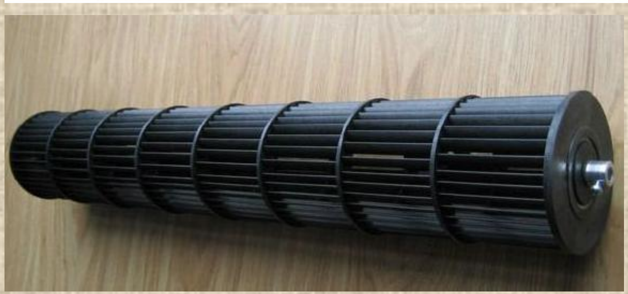
Basic items of the SH set (boiler, burner, circulation pump, flue gas exhaust, expansion tank, pipes and various components, like valves, etc) and breakdown of the burner in subitems.

Items and subitems of the HW set (solar collectors, storage tank without and with heating insulation, heating coil).

METHODOLOGY













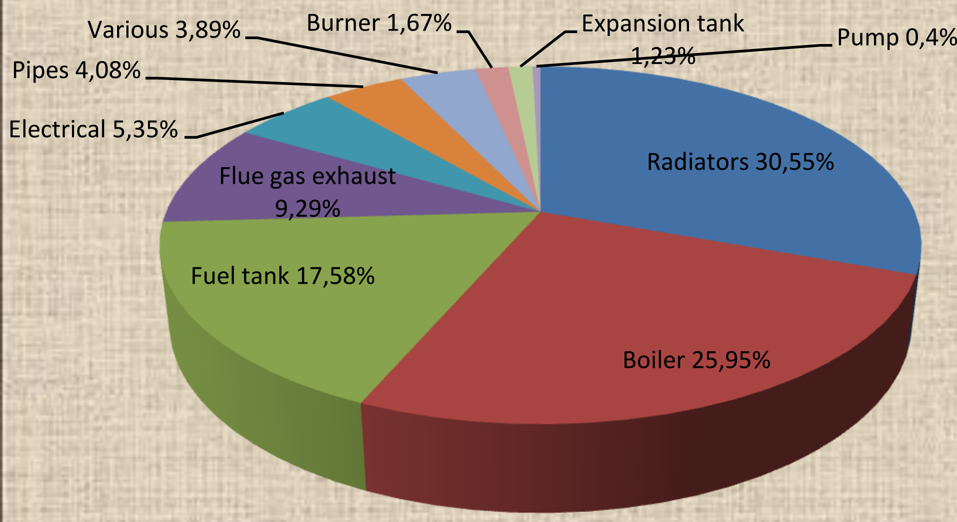




Items and subitems of the EL set (electrical cables with insulation, cable pipes, panels, electrical sockets, etc).

Items and subitems of the AC set (internal and external units, heat exchangers (condenser/evaporator), fan impellers and fan motors, refrigerant compressor, four-way valve).

RESULTS AND DISCUSSION

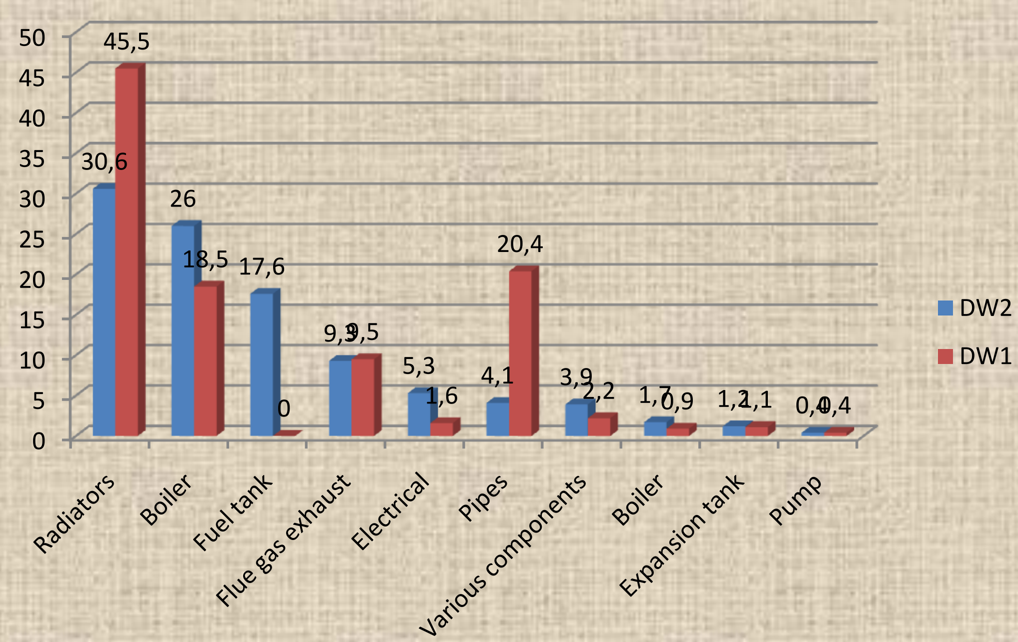


SH group / percentage mass contribution of each main item **(**relevant EL items included)
DW1: multi-family dwelling
DW2: single-family dwelling
Area-normalized results for comparison purposes!

Dominant items in mass percentage
DW1: radiators, pipes, boiler, flue gas exhaust
DW2: radiators, boiler, oil tank, flue gas exhaust.
DW1 has no tank (fuel natural gas), but has a lot of piping

due to its many apartments**.**

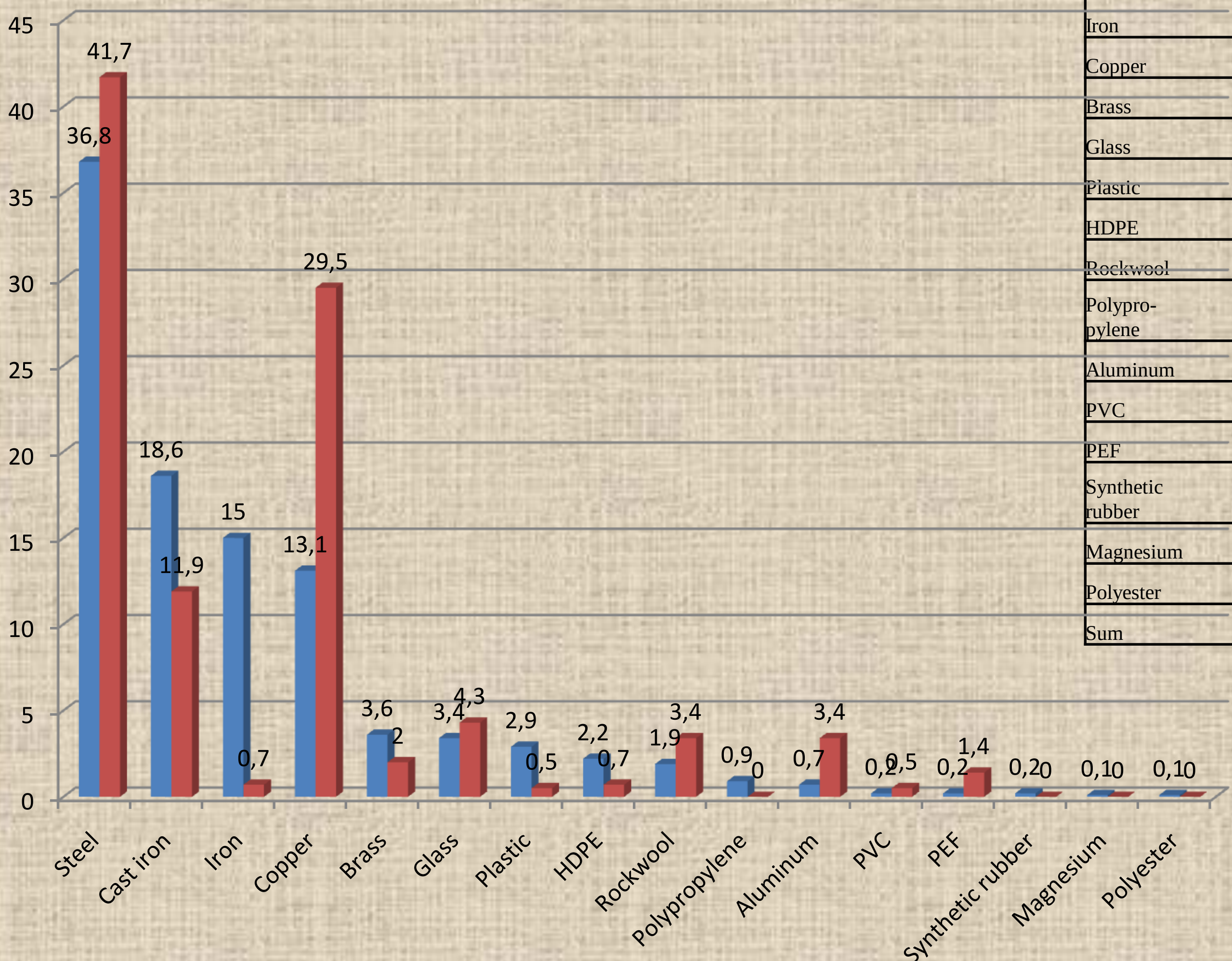
SH Items	**DW2**	**DW1**	**DW2**	**DW1**	**DW2**	**DW1**
Mass	***kg***	***kg***	***kg/m²***	***kg/m²***	***%***	***%***
Radiators	**219.0**	535.5	**1.44**	1.23	**30.6**	45.5
Boiler	**186.0**	218.0	**1.22**	0.50	**26.0**	18.5
Fuel tank	**126.0**	0.0	**0.83**	0.00	**17.6**	0.0
Flue gas exhaust	**66.6**	112.0	**0.44**	0.26	**9.3**	9.5
Electrical	**38.3**	18.5	**0.25**	0.04	**5.3**	1.6
Pipes	**29.2**	240.2	**0.19**	0.55	**4.1**	20.4
Valves, etc.	**27.8**	25.7	**0.18**	0.06	**3.9**	2.2
Burner	**12.0**	11.0	**0.08**	0.03	**1.7**	0.9
Expansion tanks	**8.8**	12.5	**0.06**	0.03	**1.2**	1.1
Pump	**2.9**	4.8	**0.02**	0.01	**0.4**	0.4
Sum	**716.7**	1178.2	**4.71**	2.70	**100.0**	100.0



RESULTS AND DISCUSSION

Similar results for the single materials contained in SH+HW groups
Dominant materials in mass percentage:
DW1: steel, copper, cast iron.
DW2: steel, cast iron, iron (due to fuel tank), copper.

SH+HW Materials	DW2	DW1	DW2	DW1	DW2	DW1
Mass	*kg*	*kg*	*kg/m²*	*kg/m²*	*%*	*%*
Steel	**334.4**	700.3	**2.20**	1.61	**36.8**	41.7
Cast iron	**169.1**	199.4	**1.11**	0.46	**18.6**	11.9
Iron	**136.7**	12.5	**0.90**	0.03	**15.0**	0.7
Copper	**119.2**	495.6	**0.78**	1.14	**13.1**	29.5
Brass	**32.9**	33.7	**0.22**	0.08	**3.6**	2.0
Glass	**30.6**	72.0	**0.20**	0.17	**3.4**	4.3
Plastic	**26.5**	9.1	**0.17**	0.02	**2.9**	0.5
HDPE	**20.2**	11.7	**0.13**	0.03	**2.2**	0.7
Rockwool	**17.5**	56.8	**0.11**	0.13	**1.9**	3.4
Polypro-pylene	**7.9**	0.0	**0.05**	0.00	**0.9**	0.0
Aluminum	**6.6**	57.6	**0.04**	0.13	**0.7**	3.4
PVC	**2.2**	7.8	**0.01**	0.02	**0.2**	0.5
PEF	**1.7**	22.8	**0.01**	0.05	**0.2**	1.4
Synthetic rubber	**1.5**	0.0	**0.01**	0.00	**0.2**	0.0
Magnesium	**1.0**	0.0	**0.01**	0.00	**0.1**	0.0
Polyester	**0.6**	0.3	**0.00**	0.00	**0.1**	0.0
Sum	**908.5**	1679.6	**5.98**	3.86	**100.0**	100.0



RESULTS AND DISCUSSION

Results for the entire EM installations of DW2:

Dominant materials in terms of mass, EE, ECO2 (UK database).

Mass dominant materials are not necessarily ranked higher in terms of ECO_2 and EE, since some of them have greater CO_2 or energy impact despite their lower mass due to their high ECO_2 and EE values per mass unit. For example copper is ranked higher than iron in terms of ECO_2 or second (after steel) in terms of EE.

The total contribution of the EM installations to the building's environmental footprint in terms of ECO_2 and EE for DW2 were estimated to be 3026.3 $kgCO_2$ (or 19.9 $kgCO_2/m^2$) and 86.6 kWh/m^2, respectively.

EM all materials	% mass	% ECO_2	% EE
Steel	**29.1**	35.67	28.47
Iron	**20.9**	15.31	12.80
Copper	**15.5**	**17.81**	**18.96**
Cast iron	**14.6**	10.67	8.92
Plastic	**5.1**	4.94	**10.04**
Brass	**3.4**	3.19	3.70
Aluminum	**2.7**	**8.59**	**10.32**
Glass	**2.6**	0.86	0.97
HDPE	**1.7**	1.20	**3.27**
Rockwool	**1.5**	0.61	0.62
Polypropylene	**1.0**	0.00	0.00
PEF	0.7	0.77	1.18
PVC	0.4	0.34	0.69
Rest materials	0.6	0.03	0.06
Total	100.0	100.00	100.00

RESULTS AND DISCUSSION

ECO2 and EE values for the SH and HW groups and the boiler and burner items.

For the SH group:
DW2: ECO2=1372 kgCO2 (or 9 kgCO2/m2) and EE=39.5 kWh/m2
DW1: ECO2=3524 kgCO2 (or 6 kgCO2/m2) and EE=33.2 kWh/m2

Benchmark value of operational thermal energy consumption for space heating in climatic zone B (Athens) ***[3]*** is 115 kWh/m2 for single dwellings (like DW2) and 91.4 kWh/m2 for apartment buildings (like DW1).

Thus, EE/OE is 36,3% for DW1 and 34,3% for DW2.

Item	ECO_2 ($kgCO_2$)		EE (kWh/m^2)	
	DW1	DW2	DW1	DW2
Burner	56	61	0.7	2.3
Boiler	438	373	3.9	9.5
Burner+Boiler	494	434	4.6	11.8
SH	3524	1372	33.2	39.5
HW	1580	933	17.6	23
SH+HW	5104	2305	50.8	62.5

[3] *C.A. Balaras, A.G. Gaglia, E. Georgopoulou, S. Mirasgedis, Y. Sarafidis and D.P. Lalas, 2007, "European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings", Building and Environment, 42 (2007) 1298–1314.*

RESULTS AND DISCUSSION

The results could be considered for the replacement of oil fired boilers in old central heating installations with new units, which is a popular energy conservation measure.

Such a replacement in the case of single-family dwellings would result to 17% annual operational thermal energy savings and a total of 335.6 ktCO2 savings, for the entire Hellenic single-family building stock **[3]**, that corresponds to annual operational savings of about 625.4 kgCO2 per single-family dwelling.

From the current analysis, the estimated ECO2 of a boiler-burner unit is 434 kgCO2. The total ECO2 for the replacement of an old boiler-burner unit should account for the values of both the old and the new unit. Accordingly, for the simple replacement of a boiler-burner, ECO2,repl=2ECO2=868 kgCO2.
Thus, ECO2,repl would be compensated by the reduced operational emissions in (868/625.4)*12= about 17 months, as a result of the improved thermal energy performance of the new unit and its operational energy savings.

The corresponding annual energy savings are estimated at about 19.6 kWh/m2 **[3]**. The EE corresponding to the boiler-burner set of DW2 is EE=11.8kWh/m2. Again, the total EE for the replacement is doubled to account for the new unit, i.e. EErepl=23.6 kWh/m2. Thus, the operational energy savings would compensate the EErepl in about 14 months, or about over two heating seasons.

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CONCLUSIONS

- Previous work for a multi-family apartment building was extended and implemented to a single-family residential building.
- The prevailing materials in terms of mass are generally the same, since the E/M installations used in the Hellenic residential buildings are similar.
- However, the normalized material quantities have different values among the two investigated typologies of a single- and multi-family building.
- The estimated ECO_2 values provide some initial guidance for the evaluation of common energy conservation measures in the context of Life Cycle Assessment.
- Results indicate that the annual operational energy savings and CO_2 abatement as a result of common actions (e.g. replacing boilers with more energy efficient units) will account for the EE and ECO_2 in relatively short time frames.
- However, a proper analysis of the embodied versus operational savings, should account for the relevant differences in achieving the anticipated savings.

FUTURE RESEARCH

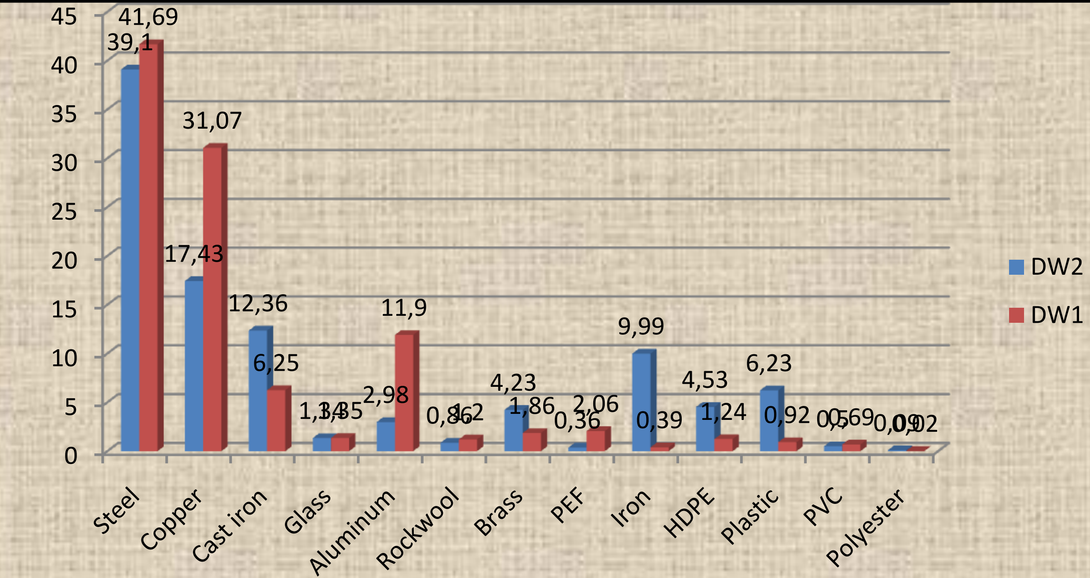
- Future work includes an extension of the current analysis for a number of different Hellenic building typologies, to conclude on the repeatability and correlation of the results.

- Similar efforts are also underway towards the collection of relevant information and perform an analysis for the building envelope construction materials that dominate a building's total EE and ECO_2.

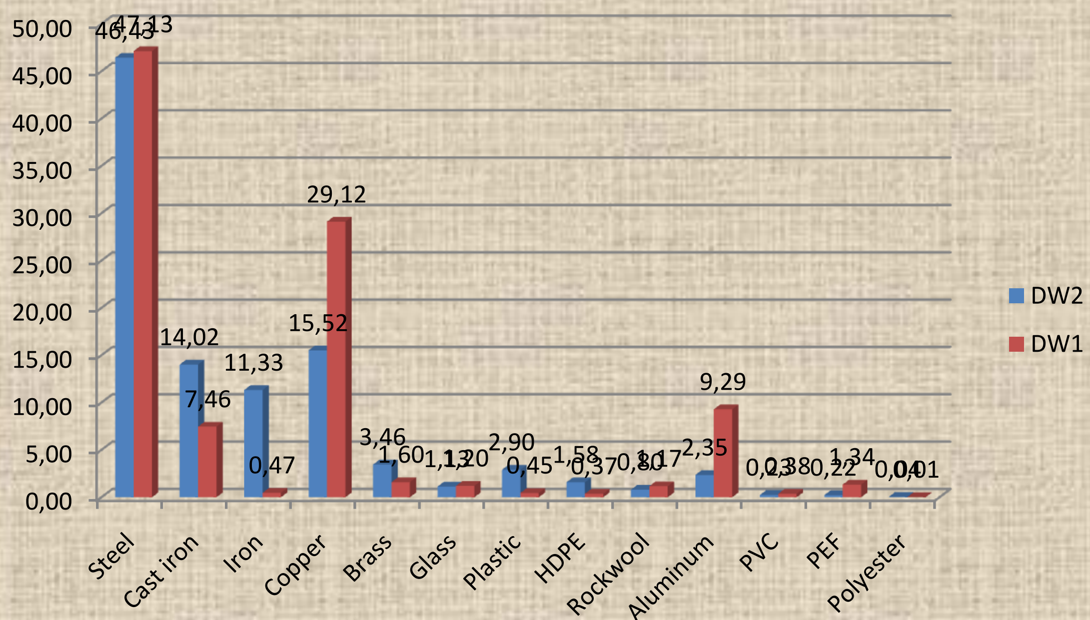
- The long term goal is to derive suitable benchmarks in order to compare the results, since no Hellenic database for EE or ECO_2 exists.

Thank you for your attention !

RESULTS AND DISCUSSION



	DW2			DW1		
	EE	EE/m²	%	EE	EE/m²	%
Steel	13375,20	87,98	**39,1**	33308,93	76,47	**41,69**
Copper	5960,35	39,21	**17,43**	24778,55	56,88	**31,07**
Cast iron	4228,50	27,82	**12,36**	4985,25	11,44	**6,25**
Glass	459,00	3,02	**1,34**	1080	2,48	**1,35**
Aluminum	1019,90	6,71	**2,98**	8924,44	20,49	**11,9**
Rockwool	293,66	1,93	**0,86**	954,81	2,19	**1,2**
Brass	1448,26	9,53	**4,23**	1480,6	3,40	**1,86**
PEF	123,29	0,81	**0,36**	1644,01	3,77	**2,06**
Iron	3417,00	22,48	**9,99**	312,5	0,72	**0,39**
HDPE	1549,34	10,19	**4,53**	989,84	2,27	**1,24**
Plastic	2129,55	14,01	**6,23**	735,78	1,69	**0,92**
PVC	169,61	1,12	**0,5**	549,1	1,26	**0,69**
Polyester	30,60	0,20	**0,09**	15,3	0,04	**0,02**



	DW2			DW1		
	ECO_2	ECO_2/m^2	%	ECO_2	ECO_2/m^2	%
Steel	1070,02	7,04	**46,43**	2406,19	5,52	**47,13**
Cast iron	323,06	2,13	**14,02**	380,87	0,87	**7,46**
Iron	261,06	1,72	**11,33**	23,88	0,05	**0,47**
Copper	357,62	2,35	**15,52**	1486,71	3,41	**29,12**
Brass	79,65	0,52	**3,46**	81,44	0,19	**1,60**
Glass	26,01	0,17	**1,13**	61,20	0,14	**1,20**
Plastic	66,93	0,44	**2,90**	23,12	0,05	**0,45**
HDPE	36,36	0,24	**1,58**	18,76	0,04	**0,37**
Rockwool	18,35	0,12	**0,80**	59,67	0,14	**1,17**
Aluminum	54,22	0,36	**2,35**	474,44	1,09	**9,29**
PVC	5,38	0,04	**0,23**	19,19	0,04	**0,38**
PEF	5,13	0,03	**0,22**	68,41	0,16	**1,34**
Polyester	0,90	0,01	**0,04**	0,45	0,00	**0,01**