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Existing buildings and HVAC systems: incidence of innovative surface finishes on the energy requirements

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Abstract

A great portion of the global energy consumption depends on existing buildings. So, energy saving and related CO_2 emission reduction are important measures. This paper analyses the incidence of innovative surface finishes on the cooling and heating energy demand of existing buildings. These easy and cheap measures preserve the little living spaces, limited height and the architectural/chromatic characteristics. The analysis is conducted for various European cities, by using a dynamic energy simulation software. The primary energy required by the HVAC systems on seasonal and annual basis is evaluated and relevant energy saving (up to 21% on annual basis) is obtained. Finally, a technical-economic analysis is performed and interesting payback values are obtained (2.5-11 years in the best cases; 2–10 years, when a tax deduction of 35% is considered).

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Keywords: building envelope; existing buildings; surface finishes; energy saving; HVAC systems

1. Introduction

In Europe, the building energy requirement is about 40% of the global energy demand. So, the EPBD recast [1] promotes energy saving in buildings and use of passive solutions. In Bellia et al. [2-3], a passive strategy based on suitable solar shading devices allows relevant reductions of the energy demand for air conditioning. A great problem is represented by the large number of historic buildings, characterised by low energy performances (Filippi [4]). The global warming (Cotana et al. [5]), the urban heat islands (Santamouris [6], Xu et al. [7]) and the cooling energy requirements of buildings (Synnefa et al. [8]) can be mitigated by means of the Albedo control, which consists in reflecting to the space the shortwave incident radiation. Ascione et al. [9] study the influence of the surface finishes on the energy requirements of the buildings. Relevant summer energy saving in school buildings (Synnefa et al. [10]) and in commercial buildings (Levinson et al. [11]) is also shown. In Pisello et al. [12], the proposed high reflective tiles for

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pitched roofs allow reducing the cooling demand of about 50% for historic residential buildings. The effects of innovative cool and low-emissivity paints are studied in Marino et al. [13]. The use of external innovative finishes on pitched roofs and walls of existing attics reduces the cooling energy requirements (up to 60%) and increases the heating energy demand (up to 10%).

The analysis reported in [13] is extended in the present paper: also the case of insulated building envelope is considered, as well as different configurations of HVAC systems and various efficiency values of the different national electric systems. The case study is an existing attic modelled with properties typical of the historical buildings, depending on the various countries (TABULA Project [14]). Traditional HVAC systems for existing residential buildings are considered. The analysis is conducted for various European cities, through a dynamic energy simulation software (Design Builder [15]) based on EnergyPlus code. The paper analyses the energy saving for heating and cooling, and the payback values obtainable by applying simple innovative surface finishes on the opaque surfaces of an existing attic. It is important to highlight that the proposed retrofitting measures are easy and cheap; moreover, they allow the preservation of the little living spaces, limited height and architectural/chromatic characteristics.

Nomenclature

α absorptance (ND)

ε emissivity (ND)

ρ reflectance (ND)

η_{gl} seasonal global efficiency of the heating system (ND)

$\eta_{thermoelectric}$ efficiency of the national electric system (ND)

Subscripts: **c**=cooling, **h**=heating, **y**=yearly

COP coefficient of performance (ND)

EPBD European Energy Performances Building Directive

HVAC heating, ventilation and air conditioning

PE primary energy (kWh/m^{2}y)

SEER seasonal energy efficiency ratio (ND)

SPB simple payback time (number of years)

TE thermal energy needs of building envelope (kWh/m^{2}y)

U thermal transmittance (W/m^{2}K)

PA Palermo **RM** Rome **MI** Milan **SV** Seville **PS** Paris **BE** Berlin

2. The proposed innovative surface finishes, the methodology and the case study

The traditional coatings herein considered as reference case are the following: internal white plaster with high $\varepsilon_{infrared}$ (0.9); red tiles on the pitched roof with high $\varepsilon_{infrared}$ (0.9) and low solar reflectance ρ_{solar} (0.3–0.4); external plaster with medium α_{solar} (0.3–0.4) and high $\varepsilon_{infrared}$ (0.9).

The innovative coatings are characterized as follows: red tile cool paint on pitched roof (ρ_{solar} =0.79; $\varepsilon_{infrared}$ = 0.89); white cool plaster on external surfaces of the vertical walls (ρ_{solar}=0.88; $\varepsilon_{infrared}$=0.9); low far-infrared emissivity plaster on internal surfaces of the building ($\varepsilon_{infrared}$=0.62), realized with traditional plaster and ceramic nanospheres. This innovative internal plaster increases the internal surface thermal resistance by 18.5-26.5% (CertiMac [16]); the use of two layers of this plaster gives an additional resistance of 1.05 $m^2K\ W^{-1}$ (Geoscience [17]).

The simulations are performed through a dynamic building simulation software [15] based on EnergyPlus calculation engine, a code validated in many works (Olsen et al. [18], Buonomano et al. [19], U.S. Department of Energy [20,21]). The simulations are carried out on a typical existing residential attic, localized in some Italian and European cities. The International Weather for Energy Calculation (IWEC) files are used. Characteristics of the historical buildings of the period 1900-1950 are considered, depending on each city [14]. Four retrofitting actions are examined [13]: action 1 (red tile cool paint on traditional tiles of the pitched roof); action 2 (action 1 + white plaster on outside surface of the vertical walls); action 3 (low emissivity plaster on inside surfaces); action 4 (= actions 1 + 3). Various cases of building envelope thermal insulation are considered: a) uninsulated; b) low insulated (3 cm) and c) medium insulated (5 cm). Traditional water boiler with radiators for winter and split-systems for summer are considered. Other properties of the building envelope, HVAC and thermoelectric systems are shown in Fig. 1. The working hours of the HVAC systems are as follows: for Palermo and Seville, 8 hours for heating and 10 for cooling; for Rome, 12 hours for heating and 10 for cooling; for Milan, Paris and Berlin, 14 hours for heating and 10 for cooling.

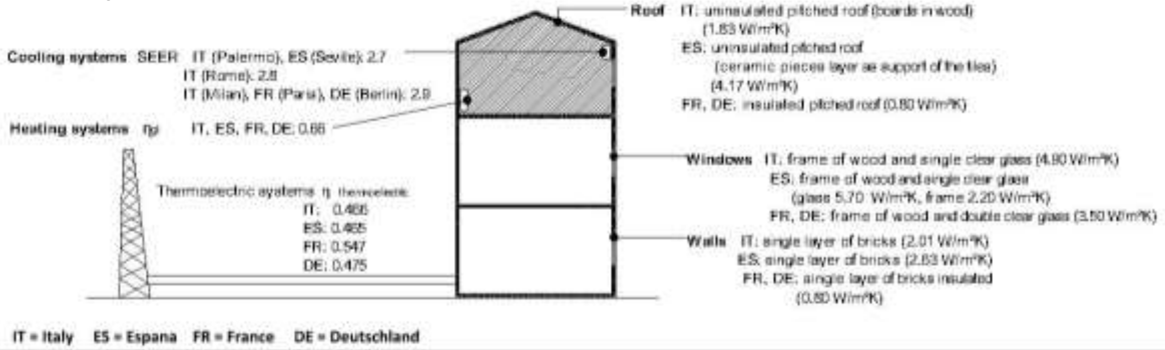

Fig. 1. Main characteristics of the building envelope, HVAC and thermoelectric systems considered for different countries proposed. From (Tabula Project, 2013 [14]; Eurostat, 2013 [22])

Primary energy requirements (PE) are evaluated starting from thermal energy for heating (TE_h) and cooling (TE_c): $PE_h=TE_h/\eta_{gl}$; $PE_c=TE_c/SEER*\eta_{thermoelectric}$. Then, SPB is calculated only for two Italian cities representative of the warm and cold climates, i.e. Palermo and Milan. The Italian electricity (0.245 €/kWh) and gas (0.08 €/kWh) tariffs are considered (Eurostat [23]). The proposed retrofitting measures are easy and cheap (5-6 €/m^2, including material cost, labour cost, security cost and enterprise profit). In the SPB analysis, also two further HVAC systems are considered: only split-systems (Palermo: winter COP=3, summer SEER=2.7); heat pump and fan-coils (Palermo: COP=2.8, SEER=2.5; Milan: COP=2.5, SEER=2.8). The case with only split-systems is not considered for Milan due to its cold climate.

3. Results

Fig. 2 shows PE demand for cooling and heating (PE_c and PE_h). The actions (1 and 2) on the external surfaces have a positive impact on PE_c (for not insulated building, the action 1 in Palermo reduces PE_c of 34.5%) and negative effect on PE_h (increases of 9.5%). Instead, the internal interventions (action 3) are suitable both in winter and summer (in Milan, PE_h is reduced by 17.8% and PE_c by 6.6%).

Yearly PE (PE_y) is reported in Fig. 3, together with the percentage variations compared to the base case with traditional finishes. The actions appear more efficient when the building envelope is not insulated. The 1st and 2nd actions are more adequate for the hottest cities (Palermo and Seville). For example, when the action 1 is considered, PE_y is reduced by 2.5-11.2%. Conversely, the same action increases PE_y in mild or

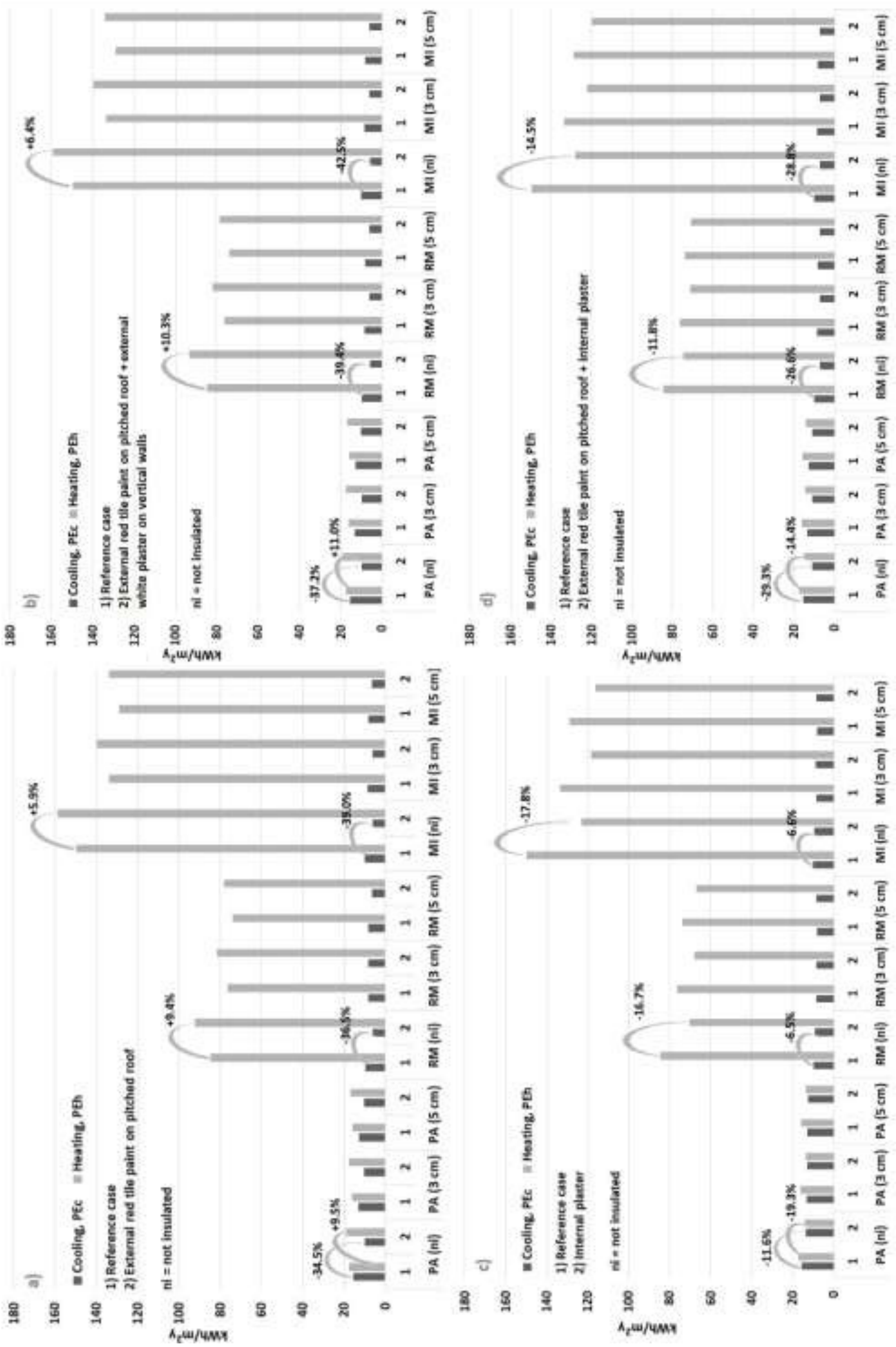

Fig. 2. Primary energy demand for cooling (PE_c) and heating (PE_h), for actions 1 (a), 2 (b), 3 (c) and 4 (d)

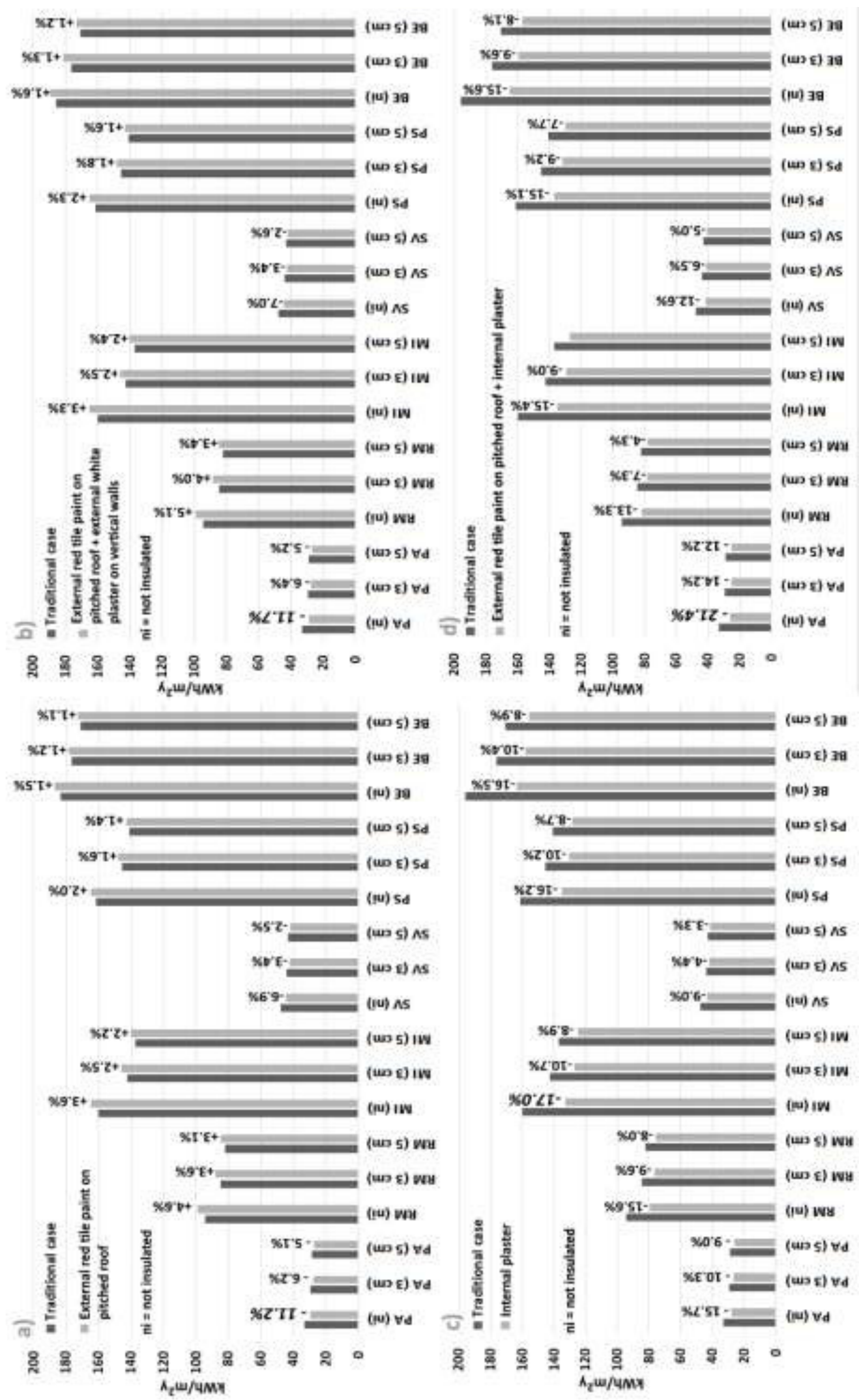

Fig. 3. Yearly (PE_y) primary energy demand for both heating and cooling, for actions 1 (a), 2 (b), 3 (c) and 4 (d)

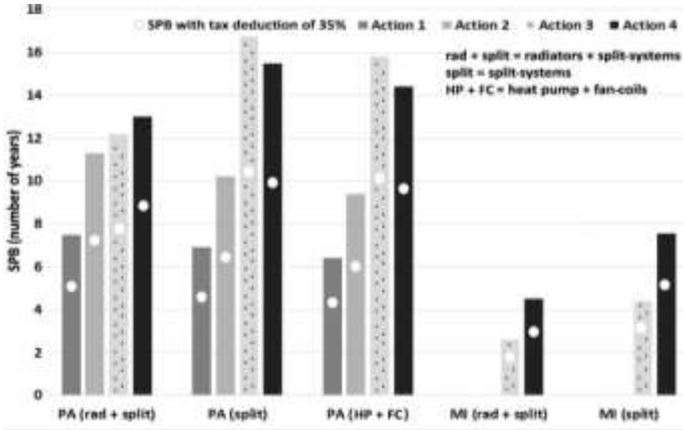

Fig. 4. Simple payback periods for the proposed retrofit measures (without and with tax deduction of 35% of the investment)

cold cities (Rome, Milan, Paris and Berlin) by 1.1-4.6%. The 3rd and 4th measures are suitable for all the cities: action 3 reduces PE_y by 3.3-17%; action 4 decreases PE_y by 4.3-21.4%.

SPB is reported in Fig. 4 (only the bars related to acceptable SPB values). In Palermo, the actions (1 and 2) on external surfaces are preferable (SPB of 6.5–11.3 years); in Milan, the action (number 3) on internal surfaces is suitable (2.5 – 4.2 years). With a tax deduction of 35%, SPB is equal to 2–10 years.

Conclusions

The paper analyses the incidence of innovative surface finishes on the cooling and heating energy requirements of existing attics. The actions on the external surfaces (on pitched roof and external walls) have a positive impact on the cooling demand (PE_c) (the action on pitched roof in Palermo reduces PE_c of 34.5%) and negative effect on the heating demand (PE_h increases of 9.5%). Instead, the internal actions are suitable in both winter and summer (in Milan, PE_h reduces of 17.8% and PE_c of 6.6%). Regarding the yearly PE (PE_y), the actions on outside surfaces are more adequate for the hottest cities (Palermo and Seville: PE_y reduces of 2.5-11.2%), while they increase PE_y in mild and cold cities (Rome, Milan, Paris and Berlin) by 1.1-4.6%. The actions on inside surfaces reduce PE_y for all the cities (3.3-17%). Simple payback of 3–11 years are obtained (2–10 years, when tax deduction of 35% is considered).

References

[1] European Parliament, Directive 2010/31/EU of The European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Off J. Eur. Union (2010).

[2] L. Bellia, F. De Falco, F. Minichiello, Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates, Appl Therm Eng, 54 (2013), pp. 190–201.

[3] L. Bellia, C. Marino, F. Minichiello, A. Pedace, An overview on solar shading systems for buildings, Energy Procedia 62 (2014), pp. 309-317.

[4] M. Filippi, Remarks on the green retrofitting of historic buildings in Italy. Historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, AICARR (2014) 31-46.

[5] F. Cotana, F. Rossi, M. Filipponi, V. Coccia, A.L. Pisello, E. Bonamente, A. Petrozzi, G. Cavalaglio, Albedo control as an effective strategy to tackle Global Warming: A case study, Applied Energy 130 (2014) 641-647.

[6] M. Santamouris, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, Solar Energy 103 (2014) 682-703.

[7] T. Xu, J. Sathaye, H. Akbari, AVC. The direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions, Building and Environment 48 (2012) 1-6.

[8] A. Synnefa, M. Santamouris, H. Akbari, Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions, Energy and Buildings 39 (2007) 1167-1174.

[9] F. Ascione, L. Bellia, P. Mazzei, F. Minichiello, Solar gain and building envelope: the surface factor, Build. Res. Inform. 38 (2010) 187–205.

[10] A. Synnefa, M. Saliari, M. Santamouris, Experimental and numerical assessment of the impact of increased roof reflectance on a school building in Athens. Energy and Buildings 55 (2012) 7-15.

[11] R. Levinson, H. Akbari, Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants 3 (2010) 53-109.

[12] A. Pisello, F. Cotana, Thermal-energy performance of high reflective tiles in historic buildings, Historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, AICARR (2014) 365-378.

[13] C. Marino, F. Minichiello, W. Bahnfleth, The influence of surface finishes on the energy demand of HVAC systems for existing buildings, Energy and Buildings 95 (2015) 70-79.

[14] TABULA Project, 2013, http://webtool.building-typology.eu/webtool/tabula.html.

[15] Evolvente Design Builder Software Version 3.2.0.067, (2013).

[16] CertiMaC. Valutazione numerica del contributo alla resistenza liminare di parete opaca verticale ed orizzontale di vernice termoriflettente a bassa emissività (UNI EN ISO 6946:2008), Report n◦110123-R-2522, Faenza, Italy, 2011 (in Italian).

[17] Geoscience, A Study of the Energy Savings that can occur when using Insuladd Solar Reflective Painton Irradiated Buildings Walls. Report, San Diego, CA, 2003. http://www.insuladd.com/media/insuladd/docs/research/R-value-Geoscience-Report.pdf.

[18] E.L. Olsen, Q.Y. Chen, Energy consumption and comfort analysis for different low-energy cooling systems in a mild climate, Energy Build. (2003) 560–571.

[19] A. Buonomano, A. Palombo, Building energy performance analysis by an in-house developed dynamic simulation code: an investigation for different case studies, Appl. Energy 133 (2014) 788–807.

[20] U.S. Department of Energy, EnergyPlus Testing with HVAC Equipment Performance Tests CE100 to CE200 from ANSI/ASHRAE Standard 140-2011,2011, pp. 1–80 http://apps1.eere.energy.gov/buildings/energyplus/energyplustesting.cfm.

[21] U.S. Department of Energy, EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2011, 2011, pp. 1–132http://apps1.eere.energy.gov/buildings/energyplus/energyplus testing.cfm.

[22] Eurostat Pocketbooks, Energy, transport and environment indicators, ISSN 1725-4566 (2013).

[23] Eurostat Data from March 2014, 2014, http://ec.europa.eu/eurostat/statistics-explained/index.php/Energypricestatistics.