Counting good: quantifying the co-benefits of improved efficiency in buildings

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Abstract

Many recent major studies, including the IPCC's Fourth Assessment Report, have attested that energy efficiency is humanity's prime option to combat climate change in the short- to mid-term. The potential to avoid CO_2 emissions cost-effectively has been reported to be significant through efficiency policies. However, the review of global research findings on the quantification of cost-effectiveness of opportunities through improved efficiency has highlighted that there is a major shortcoming in the vast majority of such calculations. It is common that such studies normally consider only direct costs in their assessment. Whereas there have been several trans-national efforts to quantify external cost, external "benefits", or co-, ancillary- or non-energy benefits are rarely monetized and included in cost-benefit analyses. Since several studies have attested that these benefits often amount to more than the direct energy benefits, the omission of these values severely distorts the results of such assessments and, therefore, it is of utmost importance to consider these for in global and national policy-making and target-setting. The aim of the present paper is to assist in laying the foundations for this process, and demonstrates this on the case of the building sector. The paper reviews and synthesises the granules of research in this field. It first provides a taxonomy of co-benefits, and then collates case studies found in the public domain in which certain co-benefits have been monetized/quantified. Then, the paper summarises the various methodologies applied for the quantification of these. Finally, it offers equations on how different co-benefits could be integrated into a more holistic cost-benefit and/or cost-effectiveness assessment.

Introduction

It has been long recognised that investment in energy efficiency and zero and low carbon technologies can yield a wide spectrum of benefits beyond the value of saved energy and reduced CO_2 emissions (e.g., Wyon 1994, Mills et al. 1995, Mills and Rosenfeld 1996, Menzies 1997). There are indications that such non-energy and non-climate benefits are especially large in the buildings sector (IPCC 2007). Some studies suggest that the total value of these non-energy benefits may in fact exceed the direct energy benefits in many cases related to improve building energy efficiency (see, for instance, Kats 2006, Schweitzer & Tonn 2002). However, such benefits are rarely, if ever, included in the cost-benefit analysis[1] and other approaches to environmental policy assessment[2] of energy-efficiency or climate change mitigation options (IPCC 2007). This is a significant omission, since if such benefits are incorporated into the CBA this may substantially change the priority order of options or the financial viability of options considered.

Therefore, benefits associated with CO_2 emission mitigation may play a crucial role in making GHG emission mitigation

1. Cost-benefit analysis precedes policy preparatory work, even if it is not a direct monetary appraisal. For instance, when carbon mitigation or energy-savings potentials are assessed, or carbon mitigation measures are ranked by cost-efficiency, a cost-benefit assessment is performed. Thus here we refer to a broader group of appraisals than just a classical project-based CBA.

2. Other approaches to environmental valuation include, *inter alia*, Cost-Effectiveness Analysis and Incremental Cost Analysis.

a higher priority if considered because they contribute to and share the costs with other global and national aims. However, as mentioned above, these benefits are often not quantified, monetized, or perhaps even identified by decision-makers and other involved stakeholders.

Therefore, the aim of this paper is to contribute to the quantitative understanding of non-energy benefits in relation to improved energy-efficiency in buildings, especially from the perspective as they might influence energy- and climate-related decision-making. The paper reviews the existing and publicly available literature on the quantification of non-energy benefits of improved energy-efficiency in buildings. It first provides a taxonomy of these benefits, and then synthesises the available case studies that have quantified non-energy benefits for certain energy-efficiency improvements worldwide. Then, it reviews the existing methods used to quantify different non-energy benefits, and proposes a method how these can be totalled.

Typology of non-energy benefits of CO_2 mitigation in buildings

The literature distinguishes two types of non-energy benefits associated with energy-efficiency improvement: co-benefits and ancillary benefits. The IPCC AR4 defined co-benefits as the benefits of policies that are implemented for various reasons including climate change mitigation as one of them (IPCC 2007). These policies have equally or to some extent other objectives than mitigation such as economic and social development, sustainability, and equity. The AR4 defines the ancillary benefits as side effects of policies aimed exclusively at CO_2 emission mitigation[3]. For the purposes of this paper, we do not distinguish between co- and ancillary benefits, but aim to catalogue and quantify all non-energy benefits.

The non-energy benefits of CO_2 emission mitigation are numerous, and it is useful to identify and classify them before their detailed assessment. Most of the existing studies do not give an explicit classification of these benefits in the building sector: typically the researchers focus on selected country case studies and list that/those co-benefit(s) which seem(s) the most important. However, there are a few classifications of benefits of CO_2 emission reduction in general in the economy which might be applied to classify the benefits from CO_2 emissions in energy using sectors. For instance, Davis et al. (2000) suggests the classification of the co-benefits into three categories - health, ecological, and economical co-benefits dividing the last category into the ancillary financial impacts such as employment change, energy security, induced technological change, and avoided costs. The IPCC AR4 lists non-energy benefits in the buildings sector in a similar way adding improved social welfare and poverty alleviation (IPCC 2007). In Table 1 we classify co-benefits and ancillary benefits of CO_2 emission mitigation in the buildings sector. We would like to note, however, that our list is not exhaustive and there might be more benefits which are not included in our classification[4].

Worldwide review of the studies quantified the impact of benefits of GHG mitigation and energy efficiency in buildings

The authors identified over two dozen of pieces of research that quantify co-benefits and ancillary benefits of CO_2 mitigation in buildings. Typically these studies quantify the physical impacts of CO_2 emission reduction in buildings and then monetize them. Table 2 presents the worldwide review of the studies; it details the methodology they used and presents the results of their calculations. The table reviews impacts both in terms of physical indicators as well as monetary ones. It is typically recommended to consider both of these, since the assumptions that are used to translate physical benefits into monetary ones, such as the value of life and health as well as comfort, are often controversial and extremely variable by research method and geographic location.

Table 2 illustrates that different types of benefits have been examined to a different extent. Thus, the avoided morbidity and mortality, the reduction of air pollution, and productivity gains are intensively studied. The authors were unable, though, to locate many pieces of research on quantification of such benefits as improved energy security, avoided costs due to increased awareness, the induced technological exchange, and a few others.

Another fact revealed by the review is that only a few regions concentrate and are the subject of research on CO_2 mitigation benefits. Thus, the USA was the subject of most of the studies, followed by a few countries of the European Union. The effects of benefits of CO_2 mitigation in the regions, where perhaps they would attract the largest attention - developing countries and transition economies, are poorly examined.

The assessment of Table 2, first, attests that the benefits of GHG emission mitigation in the buildings sector are indeed numerous for human health, environment, high quality services for people. For instance, as Milton et al. (2000), Mendell et al. (2002), Seiber (1996), Wyon (1994) calculated, advanced energy services and reduced emissions improve the physical and mental state of human health. As Aunan et al. (2000), Samet et al. (2000), and Clinch and Healy (1999) found, these health effects translate to reduction of the human mortality. Kats (2005) and SBTF (2001) estimated a significant impact of improved efficiency in buildings through a reduction of construction and demolition wastes as a part of "green building" initiative up to 99%, which makes the weatherized buildings not only energy efficient but environmentally efficient in all respects. Furthermore, Schweitzer and Tonn (2000) revealed that efficiency improvement and emission reduction may provide a number of services at a higher quality such as electricity and gas transportation with fewer losses and leaks. Table 2 shows that these and other benefits result in significant financial revenues (directly or in terms of saved costs). Milton et al. (2000), Aunan et al. (2000), National Medical Expenditure Survey (1999), Katz (2005, 2006), O'Conor (2004), Paladino and Company (2005),

3. The definitions of co-benefits and ancillary benefits of GHG mitigation vary in literature. For instance, according to the OECD workshop on the benefits of climate policy (2000), co-benefits – are signaling (monetized) effects that are taken into consideration as an explicit (or intentional) part of the development of GHG mitigation policies, and ancillary benefits indicate effects that are incidental to mitigation policies, i.e. not explicitly taken into account (Jochem and Madlener 2003). At the same time, some researchers do not differentiate between these two terms (Krupnick et al. 2000).

4. The authors of this paper welcome reader comments along these lines.

Table 1. Typology of benefits of energy efficiency and distributed energy use in the buildings sector and selected indicators for their potential quantification

Category	Non-energy benefit subcategory	Examples of concrete benefits, and potential indicators for its quantification
Health effects[1]	Reduced mortality	Higher employment, more working days due to reduced mortality. Mortality is reduced through improved indoor and outdoor air pollution, and through reduced thermal stress in better buildings (hot and cold).
	Reduced morbidity	Avoided hospital admissions, medicines prescribed, restricted activity days, productivity loss. Morbidity is reduced through the impacts above, as well as through better lighting, mold abatement, thoughtful ergonomics etc.
	Reduced physiological effects	Learning and productivity benefits due to better concentration, savings due to avoided "sick building syndrome".
Ecological effects[2]	Reduction of indoor air pollution	Similar to reduced morbidity. Indoor air quality improves through the reduction of incompletely combusted fossil fuels and biomass, through better ventilation that eliminates gaseous wastes and toxic fumes from buildings materials and activities.
	Reduction of outdoor air pollution	Similar to reduced morbidity but this category is broader including, for instance, avoided damage to building constructions. Outdoor air pollution is brought down through reduced fossil fuel burning, the minimization of the heat island effect in warm periods through reduced local energy consumption, etc.
	Construction and demolition (C&D) waste reduction benefits	Waste rate reduced due to such a vital part of "green buildings" initiative as C&D waste management that includes carefully planned "reduction, reusing, and recycling waste generated from building construction, renovation, deconstruction, and demolition" as defined by the US Environmental Protection Agency.
	Increased urban vegetation	In the case of green roofs and walls.
Economic effects	Lower energy prices[3]	Decrease in fuel and energy prices due to reduced energy demand driven by energy efficient measures implemented.
	Decreased energy bill payments	Lower energy consumption, on average, results in decreased payments for consumed energy.
	Higher lifetime earnings[4]	Higher salaries and, as a consequence, higher living standards.
	New business opportunities	New market niches for energy service companies (ESCOs) resulting in higher GDP growth.
	Employment creation	Reduced unemployment through hiring workers for ESCOs (as a consequence, reduced dole payments).
	Rate subsidies avoided[5]	Decrease in the number of subsidized units of energy sold. In most developing countries energy for the population is subsidized heavily. If energy is used more efficiently, substantial subsidies can be avoided.
	Lower bad debt write-off[6]	A decrease in the average size of bad debt written off and a decline in the number of such accounts due to reduced energy bills that become affordable for more households.
	Enhanced ability to rent out or sell energy-efficient space, higher price of real estate.	Higher real estate and rental prices due to the fact that a weatherized unit becomes more appealing with regard to its environmental and economic performance.
	Improved energy security	Reduced dependence on imported energy; reduced military spendings related to the securing of energy import sources.
	Avoided costs to support the human health, working environment, and building facilities[7]	Avoided costs of mortality, hospital admissions, medicines prescribed, restricted activity days, insurance costs, productivity loss, building maintenance.
	Improved productivity	GDP/income/profit generated as a consequence of new business opportunities and employment creation (see above).
Service provision benefits	Transmission and distribution loss reduction[8]	Lower energy consumption caused by energy efficiency measures results in a smaller amount of energy (e.g, electricity, gas) transported to the household; hence the elimination of energy losses.
	Fewer emergency (gas) service calls	Saving staff time and resources necessary for attending the emergency calls due to installation newer and more energy-efficient and reliable gas appliances.
	Utilities' insurance savings[9]	Decrease in the insurance costs of utility companies as a result of fewer gas leakages and faulty appliances (Schweitzer and Tonn 2002).
Social / political effects	Improved social welfare and fuel poverty alleviation[10]	Reduced expenditures on fuel and electricity; level of reduced fuel / electricity debt; changed number of inadequate energy service level related damages such as excess winter (or summer) deaths.
	Safety increase: fewer fires	Reduced number of fires and fire calls due to the renovation of HVAC – heating, ventilation and air-conditioning systems (fewer gas leaks, short circuits, etc.).
	Increased comfort	Normalizing of humidity and temperature indicators; air purity; reduced heat stress through reduced heat islands (less local energy consumption and evapotranspiration from urban greenery in case of green walls and roofs)
	Increased awareness	(Conscious) reductions in energy consumption resulting from installation of real-time pricing meters as a part of a "green building"; higher demand for energy efficiency measures due to a possible "keeping-up-with-the-Joneses" effect.
	Increased political popularity	Political leadership introducing wide-scale energy-efficiency measures benefiting the population have reportedly gained popularity and votes
	Benefits to disadvantaged social groups	With high-efficiency and clean cooking, African women and children can save the average of 8 km walking and several hours a day that they spend on firewood collection (Goldemberg 2000). Instead, children can go to school or women enter the workforce

Notes to Table 1:

1. May translate to economic savings and be classified in economic effects.
2. Some of indoor and outdoor air pollution effects could refer to health effects.
3. Indirect secondary impact from reduced overall market demand.
4. Better environmental conditions lead to the improved learning ability which, in its turn, is directly related to lifetime earnings.
5. Rate subsidies can be defined as lower, subsidized rates provided by utilities for their low-income customers (Schweitzer and Tonn 2002).
6. Writing off the portion of a bad debt which is not paid by customers to the utilities (Schweitzer and Tonn 2002).
7. The impacts could be partially also in health effects.
8. As weatherization programs reduce the amount of consumed (and transmitted) energy, it results in transmission and distribution loss decrease.
9. Reducing gas leaks and repair of faulty appliances (as a part of weatherization programs) decreases the insurance costs of utility companies.
10. Fuel poverty is the inability to provide adequate levels of basic energy services such as heating (DSDNI 2008).

Clinch and Healy (2001, 2003)), Schweitzer and Tonn (2002), Fisk (1999, 2000a, 2000b) and other researchers monetized non-energy benefits in the range of several thousand to several Million/Billion Euro per year in different countries that corresponds to as high as 0.003-0.029 percent of their national GDP.

HEALTH EFFECTS

Perhaps the most important non-energy benefit of providing a more energy-efficient solution is the large number of lives potentially saved through the provision of safe and energy-efficient cooking (as sometimes heating and lighting) equipment in developing countries for population segments not having access to clean energy sources. Substituting traditional biomass, charcoal, kerosene and wood burning with high efficiency electric and gas cooking stoves and electric lighting makes a significant improvement of in-house air quality and reduces such household work as gathering firewood. This latter is an important gender co-benefit.

Health co-benefits include avoided morbidity and mortality as well as their influence on productivity and, consequently, on GDP growth. These effects have been intensively studied, which can be explained by the interdisciplinary nature of the issue: it is of utmost interest for both medical doctors and environmentalists as well as for economists.

The statistics on the compliance of built environment to standard specifications does not usually include constructions with less evident but important health related problems such as inadequate ventilation (Kats 2005). However, the studies on the correlation between indoor environment and health show that better ventilation causes most environmental dissatisfaction variables to improve: e.g. according to Mendell et al. (2002), the feeling of "stuffy" air dropped by 5.3% with a reduction of concentration of the smallest airborne particles by 94%. In monetary terms, for instance, Milton et al (2000) reported that net savings of up to US$ 400/employee/yr. may be obtained through the ventilation increase due to increased productivity.

Aunan et al. (2000), Samet et al. (2000), and Clinch and Healy (1999) translated health effects into the reduction of human mortality. For example, in Ireland a total mortality benefit of a 10-year proposed energy-efficiency program is estimated as US$ 2 Billion undiscounted (Clinch and Healy 2000). It should be noted that weatherization programs are particularly beneficial in the countries with poor housing conditions where the problem of fuel poverty is especially acute (Clinch and Healy 1999).

ECOLOGICAL BENEFITS

Researches usually break down the ecological benefits into several categories and consider them separately: cleaner indoor and/or outdoor air; construction and demolition waste benefits; wastewater and sewage benefits; and fish impingement. There are numerous pieces of research that identify these ecological benefits as very significant. Thus, for instance, Kats (2005) and SBTF (2001) estimated that building up green and efficient houses reduces construction and demolition wastes up to 99%; Schweitzer and Tonn (2002) found that net present value of reduction in waste water and sewage over the lifetime of the energy-efficiency measures installed is $US 3 – 657 per participating household. There are also many studies which estimate the impact on cleaner indoor and outdoor air which are inseparable from health co-benefits; these are estimated mainly from two perspectives: better ventilation and clean-burning, more efficient cooking devices (see, e.g., Kats 2005; Kats 2006; Schweitzer and Tonn 2002; Gopalan and Saksena 1999).

SERVICE PROVISION BENEFITS

Schweitzer and Tonn (2000) and Stoecklein and Scumatz (2007) revealed that energy efficiency improvement and emission reduction might provide a number of services at a higher quality. Service provision benefits include, inter alia, transmission and distribution (T&D) loss reduction, fewer emergency service calls, utilities' insurance savings (Schweitzer and Tonn 2002). For example, T&D loss reduction ranges from US$ 33 to US$ 80 per participating household (*ibid.*). In addition, bill-related calls became less frequent after the implementation of weatherization programs in New Zealand, which amounts to savings about US$ 21.1/yr. and accounts for around 7% of the total annual energy savings of (Stoecklein and Scumatz 2007).

SOCIAL EFFECTS

Available estimations of such social co-benefit as poverty alleviation vary significantly in their scope and size. For instance, according to DEFRA (2005), measures installed through energy-efficiency schemes in the UK in the period January – December 2003 resulted in the customers being on average US$ 21.2 better off/yr. However, another study shows that cost-effective improvements in energy efficiency could cut utility costs by US$ 270-1,360 per household/yr. (European Commission 2005). Other social co-benefits include higher comfort levels and a safety increase, namely fire avoidance. Increased comfort is usually calculated through a willingness-to-pay analysis (Banfi et al. 2008). Stoecklein and Scumatz (2007) estimate that after implementing a weatherization program in New Zealand comfort benefit amounted to about US$ 140/household-yr. accounting for 43% of the total annual energy savings. As to avoided fires, net present value of this co-benefit over the lifetime of the efficiency measures installed ranges up to $US 555 per participating household (Schweitzer and Tonn 2002).

Methodology for the quantification of non-energy benefits of improved energy efficiency in buildings

Table 2 identifies the methods and techniques used by researchers around the world to quantify the impacts of non-energy and non-climate benefits of CO_2 emission reduction in different countries. The methods used range from surveys with a subsequent statistical analysis, through measurements with/without subsequent statistical analysis and simulation models, cost-benefit analysis, to expert judgements.

The IPCC AR4 recognized the existing lack of research that considers a wide range of the benefits associated with CO_2 emission reduction in buildings. The previous section mentioned that a case study typically focuses on one or several benefits; therefore for aggregation of these impacts the methodologies of their estimates should be homogeneous. Table 2 shows, however, that all these methods are heterogeneous: they approach

Table 2. Benefits of CO_2 mitigation and of energy conservation in the buildings sector and methodologies for their assessment in English-language publications

Co-benefits	Country/ region	Methodology	Impact of CO_2 emission reduction: Physical indicator	Impact of CO_2 emission reduction: Monetary indicator	References
Quantifiable health effects					
Morbidity reduction	USA, New Zealand, Denmark	• A double-blind, multiple crossover intervention • Initial self-completed background questionnaires; then shorter weekly questionnaires assessing the outcomes • Environmental measurements • Statistical analysis • Cost-benefit analysis • Literature review • Authors' adjustment/estimates	USA: A drop of concentration of the smallest airborne particles by 94% resulted a decrease of confusion scale by 3.7%, fatigue scale by 2.5%, the feeling of "stuffy" air 5.3%, of "too humid" by 7.0%, of "too cold" by 5.5% and "too warm" by 3.5%. USA: Cooler temperatures within the recommended comfort range resulted in a decrease of the chest tightness by 23.4% per each 1°C decrease. Denmark: Better thermal air quality led to better concentration of 15% of respondents and a 34% decrease "sick building syndrome*" cases.	USA: Improved ventilation may result in net savings of Euro 302/employee-yr. that on a national scale represents productivity gain of Euro 17 billion/yr. USA: NPV** over the lifetime of improved ventilation can reach as hight as Euro 1,652/hh. USA: Better ventilation and indoor air quality reduce influenza and cold by 9-20% (ca 16-37 million cases) that translates into savings of Euro 4.5-10.6 billion/yr. New Zealand: Health benefits due to a weatherization program amount to Euro 35/hh-yr. or 18.5% of the total annual energy savings of a household.	Mendell et al. 2002; Milton et al. 2000; Schweitzer and Tonn 2002; Wyon 1994; Stoecklein and Scumatz 2007; Fisk 1999; Fisk 2000a
Mortality reduction	Hungary; USA, Ireland, Norway	• Bottom-up study (with Monte Carlo simulation) • Statistic time-series analysis: semi-parametric log-linear model, a weighted 2-stage regression • Analysis of mortality statistics with a population of a similar country as the control group	USA: Every 10 g/m^3 increase in ambient particulate matter (the day before deaths occur) brings a 0.5% increase in the overall mortality. Ireland, Norway: The share of excess winter mortality attributable to poor thermal housing standards is 50% for cardiovascular disease and 57% for respiratory disease.	Hungary: Energy saving program resulted in the total health benefit of Euro 489 million/yr. due to a decrease of chronic respiratory diseases and premature mortality. Ireland, Norway: A total mortality benefit of a hypothetical thermal-improving program is Euro 1.5 billion (undiscounted) for a study in the left column.	Aunan et al. 2000; Samet et al. 2000; Clinch and Healy 1999
Environmental (ecological) co-benefits					
General environmental benefits	New Zealand	• Direct computation • Willingness to pay/to accept, contingent valuation, other survey-based methods	NZ: Benefits to the environment gained after the weatherization program amount to Euro 44/hh.-yr. in 2007 that accounts for around 18.7% of the total annual energy expenditures saved		Stoecklein and Scumatz 2007
Cleaner indoor air	USA	• Literature review • Data analysis	US: A sample considered a reduction of concentration of the smallest airborne particles by 94% US: The reduction in the emission/yr. of a green school as compared to the average practice: - 1,200 pounds of NOx - a principal component of smog - 1,300 pounds of SO_2 - a principal cause of acid rain - 585,000 pounds of CO_2 - GHG and the principal product of combustion - 150 pounds of coarse particulate matter (PM10) – a principal cause of respiratory illness and an important contributor to smog.		Mendell et al. 2002; Kats 2005

Co-benefits	Country/ region	Methodology	Impact of CO_2 emission reduction		References
			Physical indicator	Monetary indicator	
Fish impingement	USA	• Literature review • Authors' adjustment/estimates	USA: NPV of reduction in fish impingement over the lifetime of weatherization measures is Euro 17.6/hh.		Schweitzer and Tonn 2002.
Waste water and sewage	USA	• Literature review • Authors' adjustment/estimates	USA: NPV of reduction in waste water and sewage over the lifetime of weatherization measures is Euro 2.6 – 495.3/hh.		Schweitzer and Tonn 2002
Construction and demolition waste benefits	USA	• Statistical analysis • NPV analysis with a 7% DR over 20 years	USA: Construction and demolition diversion rates are 50-75% lower in green buildings (with the maximum of 99% in some projects) as compared to an average practice USA: A sample of 21 green buildings submitted for certification, 81% of such buildings reduced construction waste by at lease 50%, 38% of such buildings reduced construction waste by 75% or more		SBTF 2001; Kats 2005
Reduction in air pollution (indoor + outdoor)	USA	• Literature review • Authors' adjustment/estimates • Statistical analysis	USA: A green school emits 544 kg of NO_x , 590 kg of SO_2, 265 tonnes of CO_2, 68 kg of coarse particulate matter (PM10) less in comparison with the average practice	USA: The study in the left column results in NPV Euro 0.4/ft^2 (~Euro 0.037/m^2) over 20 yr. USA: NPV of air emission reduction (CO_2, SO_x, NO_x, CO, CH_4, PM) over lifetime of the measures is (all in thousand Euro/hh: a) from natural gas burning 30.2 - 37.7; b) from electricity consumption Euro 118-185; c) air emissions of heavy metals is 0.75-12.8	Schweitzer and Tonn 2002; Kats 2005; Kats 2006
Economic co-benefits and ancillary financial impacts					
Indirect secondary impact from reduced overall market demand and resulting lower energy prices market-wide	USA	• NPV analysis with a 7% DR over 20 years • Literature review • Simplified quantification of the effect of renewable energy/energy efficiency on gas prices and bills • Using a range of plausible inverse elasticity estimates	USA: Efficiency-driven reductions in demand results in a in long-term energy price decrease equal to 100% to 200% of direct energy savings; assuming the indirect price impact of 50% over 20 years from an efficient school design, the impact of indirect energy cost reduction for new and retrofitted schools has NPV EUR 0.21/m^2 USA: 1% decrease of the national natural gas demand through energy efficiency and renewable energy measures leads to a long-term wellhead price reduction of 0.8% - 2%; the indirect monetary savings from this price decrease amounted to 90% of the direct monetary savings that it Euro 14.6 million for all customers (cumulative 5-year impact, 1998-2002, over June-September peak hours) USA: 1% reduction in natural gas demand result in a 0.75-2.5% reduction in the long-term wellhead prices.		Kats 2006; Wiser et al. 2005; O'Connor 2004; Platts Research &Consulting 2004
Enhanced learning in 'greened' buildings	USA	• Review of the financial benefits of education	Better environmental condition lead to enhanced learning abilities; a 3-5% improvement in learning and test scores is equivalent to a 1.4% lifetime annual earnings increase; an increase in test scores from 50% to 84% is associated with a 12% increase in annual earnings.		Hanushek 2005
Employees' retention: avoided reduced-activity days	USA, The State of Washington, Ireland	• Statistical analysis • Literature review • Bottom-up model • NPV analysis with a 7% DR over 20 years • A walk-through assessment of	USA: The improved quality of schools increases teacher retention by 3% USA/The State of Washington: "Greening" schools could bring 5%/yr. of improvement in teacher retention	USA : if the cost of teacher loss is 50% of salary, the left column tops study equals to a saving of Euro 0.28/m^2 if ~214 m^2/teacher is assumed USA/The State of Washington (left column): Savings of USD 160 thousand/yr during 20 years (not discounted)	Buckley et al. 2005; Kats 2005; Paladino & Company 2005; Clinch and Healy 2001

Co-benefits	Country/ region	Methodology	Impact of CO_2 emission reduction		References
			Physical indicator	Monetary indicator	
		schools • Survey		Ireland: The annual value of the morbidity benefits of the energy efficiency program is Euro 58 million excl. reduced-activity days and Euro 66.6 million incl. them	
Improved productivity	USA	• Case studies on documented productivity gains • Empirical measurements • Computer-based literature searches, reviews of conference proceedings, and discussions with researchers • Multivariate linear regression analysis of student perfromance data • Log-linear regression model • Statistical analysis • Questionnaire • NPV analysis with a 7% DR over 20 years	USA: In well day-lighted buildings: labor productivity rises by about 6–16%, students' test scores shows ~20–26% faster learning, retail sales rise 40%. USA: Students with the most day-lighting show 20% - 26% better results than those with the least day-lighting USA: The ventilation rates less than 100% outdoor air and temperature higher than 25.4˚C result in lower work performance Canada: A new ventilation system improved the productivity of co-workers by 11% versus reduced productivity by 4% in a control group USA: After building retrofitting, absenteeism rates dropped by 40% and productivity increased by more than 5%; after moving to a retrofitted facility two business units monitored 83% and 57% reductions in voluntary terminations versus a c control group with 11% reduction in voluntary termination of employment	USA: The productivity can improve by 7.1%, 1.8%, and 1.2% with lighting, ventilation, and thermal control by a tenant; an average workforce productivity increase is 0.5% - 34%/each control type. A 1% increase in productivity (~ca 5 minutes/day) is equal to Euro 452–528/employee-yr. or Euro 0.21/m^2-yr.; a 1.5% increase in productivity (~ ca 7 minutes/day) is equal to ~Euro 754/employee-yr. or EUR 0.35/m^2-yr. USA: More comfortable temperature and lighting results in productivity increase by 0.5%-5%; considering only U.S. office workers, such a change translates into an annual productivity increase of roughly Euro 15–121 billion.	Lovins 2005; Fisk 2000a; Fisk 2000b; Heschong Mahone Group 1999; Federspiel 2002; Menzies 1997; Kats 2003; Pape 1998; Shades of Green 2002
Avoided unemployment	USA	• Literature review • Authors' adjustment and calculations	NPV of avoided unemployment over the lifetime of weatherization measures is Euro 0 – 137.9/hh.		Schweitzer and Tonn 2002
Lower bad debt write-off	USA	• Literature review • Authors' adjustment/estimates	NPV of lower bad debt write-off over the lifetime of weatherization measures is Euro 11.3 – 2,610/hh.		Schweitzer and Tonn 2002
Employment creation	USA	• NPV analysis with a 7% DR over 20 years • Literature review • Authors' adjustment/estimates • Statistical assessment of the 5-year the energy efficiency programs	USA: Green schools create more jobs than conventional schools: the long-term employment impact of increased energy efficiency may provide Euro 0.21/m^2 of benefits USA: NPV of direct and indirect employment creation over the lifetime of the measures is Euro 86.7 – 3.2 thousand/hh. (note: this benefit occurs only one time in year weatherization is performed) USA: Energy efficiency investment of Euro 85.2 million in the Massachusetts economy in 2002 created 1780 new short-term jobs; in addition, lowered energy bills for participants and for Massachusetts resulted in additional spending, creating 315 new long-term jobs; energy efficiency jobs added Euro 104.8 million to the gross state product, including Euro 48.2 million in disposable income (in 2002 in Massachusetts)		Kats 2005; Schweitzer and Tonn 2002; O'Connor 2004; Kats 2005

Contents Keywords Authors

Co-benefits	Country/ region	Methodology	Impact of CO_2 emission reduction		References
			Physical indicator	Monetary indicator	
Rate subsidies avoided	USA	• Literature review • Authors' adjustment/estimates	NPV of avoided rate-subsidies over the lifetime of weatherization measures is Euro 4.5 – 52.8 /hh.		Schweitzer and Tonn 2002
National energy security	USA	• Literature review • Authors' adjustment/estimates	NPV of enhanced national energy security over the lifetime of weatherization measures is Euro 56.5 – 2,488/hh.		Schweitzer and Tonn 2002
Service provision benefits					
Transmission and distribution loss reduction	USA	• Literature review • Authors' adjustment/estimates	USA: NPV over the lifetime of weatherization measures installed ranges Euro 24.9 – 60.3/hh.		Schweitzer and Tonn 2002
Fewer emergency gas service calls	USA	• Literature review • Authors' adjustment/estimates	USA: NPV of fewer emergency gas service calls over the lifetime of weatherization measures is Euro 29.4 – 151.5/hh.		Schweitzer and Tonn 2002
Utilities' insurance savings	USA	• Literature review • Authors' adjustment/estimates	USA: NPV of utilities insurance cost reduction over the lifetime of weatherization measures is Euro 0 – 1.5/hh.		Schweitzer and Tonn 2002
Decreased number of bill-related calls	New Zealand	• Direct computation • Willingness to pay, willingness to accept, contingent valuation and other survey-based methods	Bill-related calls became less frequent after the implementation of weatherization program, which amounted savings of NZ$30 (~Euro 15.9/hh-yr.) that is 7% of the total saved energy costs		Stoecklein and Scumatz 2007
Social co-benefits					
Improved social welfare and poverty alleviation	UK	• Survey monitoring the impact of energy company schemes which were set up to fuel poverty	UK: Energy efficiency schemes applied to 6 million households in January-December 2003 resulted in the average benefit of Euro 12.7/hh-yr.		DEFRA 2005
Safety increase: fewer fires	USA	• Literature review • Authors' adjustment/estimates	USA: NPV over the lifetime of the measures installed is Euro 0 - 418/hh.		Schweitzer and Tonn 2002
Increased comfort	Ireland; New Zealand	• A computer-simulation energy-assessment model • Direct computation • Willingness to pay, willingness to accept, contingent valuation and other survey-based methods	Ireland: A household temperature once the energy efficiency program has been completed increased from 14 to 17.7˚C. The analysis showed that comfort benefits peak at year 7 and then decline gradually until year 20.	Ireland: The total comfort benefits of the program for households (described in the left column) amount to Euro 473 million discounted at 5% over 20 years; New Zealand: Comfort (incl. noise reduction) benefits after the weatherization program estimated as Euro 103/hh.-yr. that is 43% of the saved energy costs	Clinch and Healy 2003; Stoecklein and Scumatz 2007.

Notes to Table 2:
*Sick building syndrome describes the situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified (EPA 1999).
**Here and further in the table the net present value is abbreviated as NPV and the discount rate as DR.
***Here and further in the table a household is abbreviation as hh.

the different benefits using different approaches and they apply different assumptions. The overall aggregated impact of the benefits of CO_2 emission mitigation in the buildings sector on the costs of mitigation potential is difficult to estimate. Therefore, to conduct a comprehensive assessment of the impacts of these benefits their physical and monetary estimates for each of the benefits and each of the world region using a common approach and common assumptions would be crucial.

The impact of benefits of CO_2 emission reduction in the buildings sector could be estimated using the following considerations. The costs of CO_2 mitigation of a technological option are estimated using the supply curve method as:

$$AC_{it} = \frac{I_i \times a_i - \sum_{j-1}^{n} B_{itj}}{\Delta E_{it}}$$

where

AC_{it} average costs of energy conserved in year t due to application of technology i

I_i investment costs of technology i

a_i annuity factor of technology i

ΔE_{it} energy conserved in year t due to application of technology i

B_{itj} monetized co-benefit j in year t due to application of technology i

The annuity factor is calculated as:

$$a_i = \frac{(1+DR)^{n_j} \times DR}{(1+DR)^{n_j} - 1}$$

where

DR discount rate

n_j lifetime of technology i

$$B_{itj} = \Delta E_{ti} \cdot \alpha_{ij} \cdot P_{jt}$$

where

ΔE_{it} energy conserved in year t due to application of technology i

α_{ij} energy elasticity of co-benefit j due to application of technology i

P_{jt} a monetary estimate associated with a unit of co-benefit j in year t

Examples of such a calculation are provided below.

1. Co-benefit: saved energy costs ($\alpha_{ij} = 1$)

$$B_{i,Energy,t} = \Delta E_{ti} \cdot P_{Energy,t}$$

where

$P_{Energy,t}$ – energy price in year t

2. Co-benefit: avoided CO_2

$$B_{i,CO_2,t} = \Delta E_{ti} \cdot EF_{i,CO_2} \cdot P_{CO_2,t}$$

where

$\Delta E_{i,CO2}$ – emission factor of fuel saved

$P_{CO2,t}$ – price of CO_2 in year t

3. Co-benefit: reduced mortality

$$B_{i,Reduced\ Mortality,t} = \Delta E_{ti} \cdot \alpha_{i,Reduced\ Mortality} \cdot P_{Reduced\ Mortality,t}$$

where

$\alpha_{i,Reduced\ Mortality}$ – mortality avoided due to application of technology i per unit of energy saved

$P_{Value\ of\ Statistical\ Life,t}$ – estimated value of statistical life in year t

It is important to note, however, that the results of such calculations should be used with caution. The shortcomings of monetising and adding all non-energy benefits include:

- Often it is not possible to entirely compartmentalise co-benefits. Some of them will inevitably overlap, sometimes one is the result of another (such as reduced air pollution and improved health), and thus there might be some double-counting of certain benefits (although if the same impact results in clearly different monetary benefits, this should not be considered as double-counting).
- As noted above, monetising certain quantified benefits (such as value of life and health as well as comfort) is extremely controversial and their translational coefficients are widely variable among methods (e.g., direct computation vs. sophisticated time-series analysis; questionnaires vs. environmental measurements, etc.), authors, and even geographic regions.
- While the co-benefits are rather universal, their values are very case- and geographic location-specific. Therefore it is hard to derive general regional, national or global policy-related conclusions based on such quantification and synthesis. Substantially more research is needed on establishing the validity of generalised non-energy benefit calculations at a regional scale, or at least that goes beyond specific cases.

Conclusions

When societal interests are considered, associated co-benefits (along with accompanying indirect costs) related to energy-efficiency measures should be included in cost-benefit assessments that support decision-making processes whether certain measures/actions are justified on a societal basis or not, or that ranks such measures. Similarly, ancillary benefits are important determinants of private-level decision-making. At the same time, there are a limited number of potential studies or other cost/benefit assessments related to energy efficiency/

CO_2 emission mitigation strategy setting that incorporate such costs/benefits into the analysis.

The purpose of this paper was to take a first step into the direction of synthesising existing knowledge on the quantification of non-energy benefits of improved energy-efficiency in buildings, as well as proposing a methodology to add such benefits so that these can enter into the standard cost-benefit assessment-based decision-making frameworks. The paper first provided a taxonomy of non-energy benefits, cataloguing them into health, ecological, economic, service provision, and social/political benefit categories. Next, the paper reviewed the world literature on available studies quantifying non-energy benefits of improved energy-efficiency in buildings. It reported these results in a comparable framework as much as the sources allowed.

The review attested that co-benefits indeed comprise a substantial share of the direct energy benefits. Many individual benefits monetised valued as much as 19–43% of the saved energy costs. The group with the typically largest financial value of co-benefits as compared to the direct energy benefits is economic benefits estimated over the lifetime of a complex weatherization measures, although this result is inductive rather than deductive.

The paper suggested a generalised methodology for adding monetised co-benefits in order to enable them to enter traditional cost-benefit and cost-efficient analyses-based decision-making frameworks, such as GHG or energy-efficiency potentials assessments, prioritisation of policies or targeted technologies. The paper also highlighted the potential caveats of such additions and indicated that there is need for substantial further research on the subject.

However, the importance of the issue remains. Cases covered in this paper suggested that at least 9 groups of researchers monetized non-energy benefits in the range of several thousand to several million Euro per year in different countries that corresponds to as high as 0.003-0.029% of their national GDP. This substantiates the argument that it is time that the inclusion of non-energy benefits into high-level decision-making and priority-setting should be the mainstay of further research in this area.

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