Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe

WP5 Social welfare

Final report: quantifying energy poverty-related health impacts of energy efficiency

D5.4 (final report)

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List of abbreviations

CI – Confidence Interval
COMBI – "Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe" project
DALY – Disability Adjusted Life Years
ECWDi – Excess Cold Weather Deaths Index
ECWDs – Excess Cold Weather Deaths
EU – European Union
EU SILC – European Union Survey on Income and Living Conditions
EU-28 –European Union, 28 member states
EWDi – Excess Winter Deaths Index
EWDs –Excess Winter Deaths
HDDs –Heating Degree Days
nZEB –net Zero Energy Building
PAF –Population Attributable Fraction
VOLY –Value of a Life Year
VSL –Value of a Statistical Life
WHO –World Health Organization

1 Executive Summary

The main objective of the COMBI project (Calculating and Operationalizing the Multiple Benefits of Energy Efficiency in Europe) was to capture the multiple impacts of energy efficiency while using the same energy activity data in various fields of research and policy: air pollution, resource efficiency, social welfare, economy and energy system/security. This report has been renamed to reflect a narrower scope adopted for the social welfare work package – public health co-benefits in relation to energy poverty. Air pollution-related public health aspects have been explored in COMBI report D3.4.

According to the European Union's Survey on Income and Living Conditions (EU SILC), 9.4% of European Union's population were unable to keep their homes adequately warm and 15.2% lived in residential housing characterized by a leaking roof, damp walls, floors or foundation, and rot in window frames or floors in 2015 – base year for COMBI assessment. Indoor cold is related to excess morbidity and mortality due to respiratory and cardiovascular diseases during the cold season. Indoor dampness is related to mould growth, which in turn may give rise to asthma. Energy efficiency measures applied in the existing residential housing, such as building envelope insulation, replacement or installation of heating, ventilation and air conditioning systems are believed to mitigate the extent of these health conditions. Improved energy efficiency standards of new buildings are believed to prevent from energy poverty-related health implications.

This report quantifies the impact of energy efficiency interventions on energy poverty-related public health conditions – excess cold weather deaths due to indoor cold exposure and asthma due to indoor dampness exposure. To evaluate the current extent of burden of disease in relation to these residential housing-related conditions, the standard excess winter deaths formula has been further developed to account for recent methodological criticism – excess *cold weather* deaths have been quantified instead. Burden of disease approach has been used to evaluate the extent of asthma morbidity due to indoor dampness. The future projections assumed that the annual burden of disease remained the same in relation to all other factors with the exception of changes in the two factors at the focus of COMBI – indoor cold and indoor dampness (ceteris paribus). The prevalence of indoor cold and indoor dampness is modelled in relation to the extent and type of changes in the residential housing stock and the extent of social welfare policies.

Excess cold weather deaths accounted for around 323 000 cases annually in 1996-2014 in the EU-28. Out of those, around 70 000 on average annually could be attributed to indoor cold exposure. The burden of disease of asthma attributable to indoor dampness amounted to over 71 000 Disability Adjusted Life-Years (DALYs) in 2015 in the EU-28.

There is a mismatch between those who can afford energy efficiency retrofits and those who need them the most and would benefit from them the most (not only energy savings, but also improved health). Comparing the extent of the energy efficiency interventions in the residential sector under both scenarios in 2030 and the current prevalence of indoor cold and indoor dampness, in theory diverting all of the projected resources to the socially vulnerable should eradicate nearly all premature excess cold weather deaths and indoor dampness-related asthma ("socially vulnerable first" social policy scenario). The societal value of public health co-benefits would be maximized.

The public health impact of energy efficiency improvement actions in 2030 in the EU-28 ranges from a minimum of just over 3 000 of premature deaths avoided due to indoor cold under COMBI reference scenario coupled with a weak social policy to around 27 500 of avoided premature deaths under COMBI efficiency scenario coupled with a strong social policy; and a minimum of 2 700 DALYs of asthma morbidity avoided due to indoor dampness under COMBI reference scenario coupled with a weak social policy to around 25 000 DALYs under COMBI efficiency scenario coupled with a strong social policy.

The associated economic value of avoided annual public health damage in 2030 ranges from 323 million EUR to 2.5 billion EUR due to premature mortality due to indoor cold; and from 338 million EUR to of 2.9 billion EUR due to asthma morbidity due to indoor dampness.

Accelerated energy efficiency policies coupled with strong social policies could deliver additional co-benefits in the year of 2030 of around 24 500 avoided premature deaths due to indoor cold and the associated avoided economic damage of 2.2 billion EUR, and around 22 300 DALYs of avoided asthma due to indoor dampness and the associated avoided economic damage of 2.6 billion EUR.

Keywords: energy efficiency, multiple benefits, co-benefits, energy poverty, fuel poverty, poverty, social policy, human health, public health, health, asthma, excess winter deaths, excess cold weather deaths, indoor cold, indoor dampness, burden of disease, mortality, morbidity, well being, climate change, climate change mitigation, greenhouse gas emissions, buildings, building retrofit, building renovation, European Union, low-carbon transition, decarbonisation, energy transition, green economy, low-carbon economy, impact pathway, cost-benefit analysis.

2 Background

2.1 Project description

The COMBI project aims at quantifying the multiple non-energy benefits of energy efficiency. It is coordinated by the Wuppertal Institute for Climate, Environment and Energy and implemented together with the research partners University of Antwerp, University of Manchester, Copenhagen Economics and ABUD/Advanced Buildings and Urban Design. The multiple benefits of energy efficiency are gaining relevance in the research and the current policy discourse, but scientific evidence is yet scarce and scattered. Therefore, this projects will gather existing approaches and evidence from the EU area, develop modelling approaches and come up with consolidated data on different benefits such as emissions (effects on health, ecosystems, crops, built environment), resources (biotic/abiotic, energy/non-energy), social welfare (disposable income, comfort, health), macroeconomy (labor market, public finance, GDP), and the energy system (grid, supply-side, energy security). All project outcomes will be available at an open-source online database and be analysable via a graphic online-visualisation tool for personalising the findings as to their geographic location and selected benefits. To this end, the development of an aggregation methodology is of central importance to avoid double-counting and presenting the various benefits on their various dimensions. Finally, insights for policy relevance will be derived and policy recommendations will be elaborated to facilitate the communication of the non-energy benefits in the relevant policy areas. In addition, the project is in touch with on-going processes of how to include multiple energy efficiency benefits into policy evaluation.

2.2 Aim of this report

Based on the literature reviews conducted for individual multiple impacts (MI), the second main step of the COMBI project is to develop a methodology to quantify and monetise MIs. The COMBI approach follows the additionally principle: Only additional effects (both energy and non-energy related impacts) relative to an action baseline are considered. To quantify impacts, a set of energy efficiency (EEI) actions was defined (see D2.2 report). For these actions, energy saving potentials in the year 2030 have been developed reflecting official EU scenarios. This report includes methodology description and the actual quantification and monetization of multiple impacts using the COMBI scenarios that account for energy efficiency potentials.

This report deals with the quantification and monetisation of public health impacts in relation to energy poverty induced by deployed energy efficiency measures in the residential housing sector. Public health impacts due to air pollution co-impacts are discussed in COMBI report D3.4.

This report includes

- Methodologies for assessment and monetisation of public health co-benefits related to energy poverty as a result of energy efficiency impact actions;
- Results of public health impacts based on COMBI energy activity pathways for 2015 and 2030;
- Discussion and highlights for future research.

2.3 Acknowledgements

The author of this report would like to thank to all COMBI project partners and external advisors who have helped to shape this research at different stages throughout the project: Sergio Tirado-Herrero (RMIT Europe, Spain), Ian Hamilton (UCL Energy Institute, UK), Harriet Thompson (University of Birmingham, UK), Lisa Emberson (University of York and SEI York, UK); Diego Azqueta-Oyarzun (University of Alcala, Spain), Lisa Ryan (University College Dublin, Ireland), Ray Galvin (University of Cambridge, UK and University of Aachen, Germany).

3 Scope of investigation

3.1 Overview

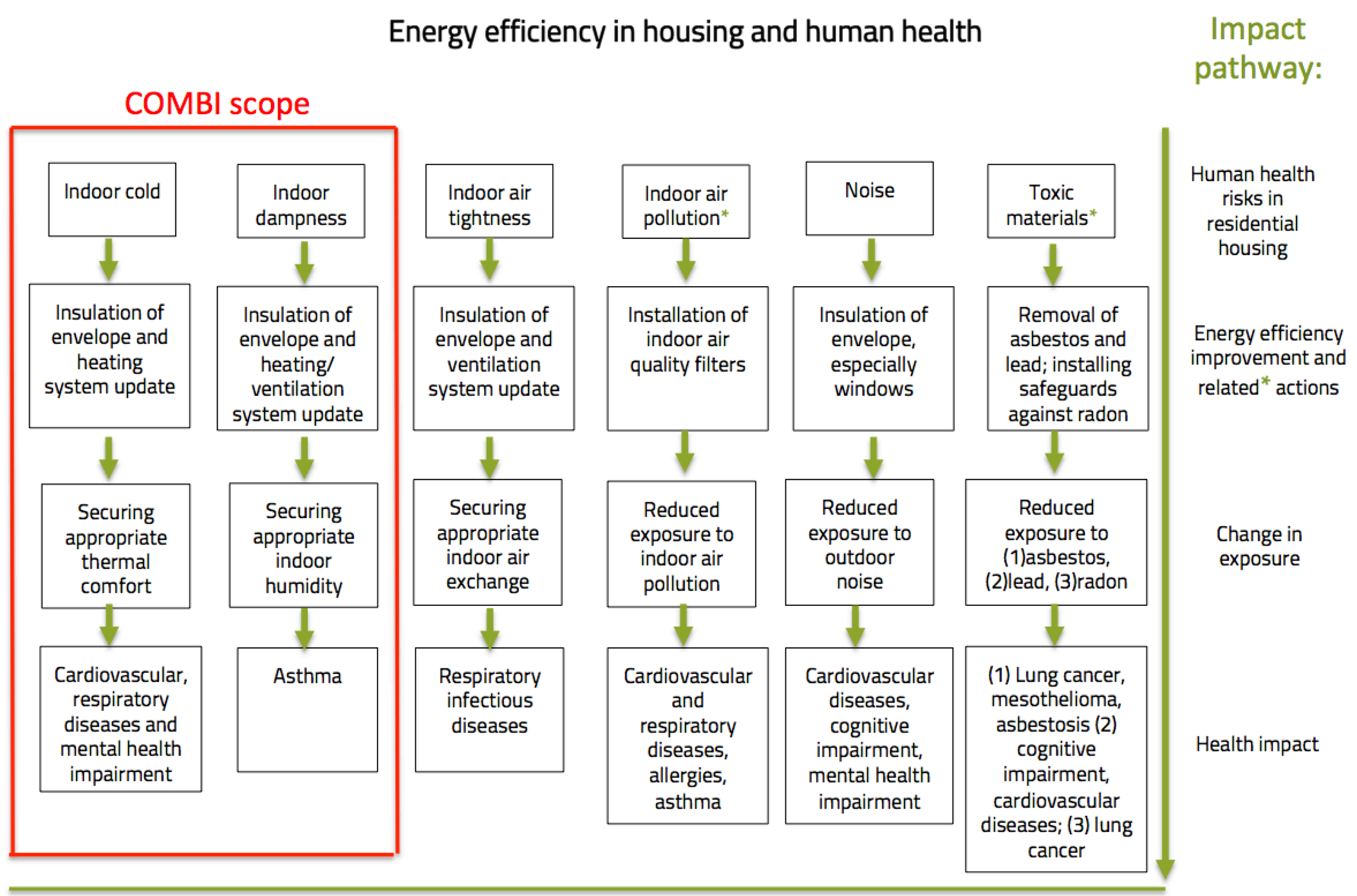
As the social welfare literature review has informed (Mzavanadze, Kelemen, & Urge-Vorsatz, 2015), social welfare benefits happen in two of the three studied sectors in COMBI – transport and buildings. In the buildings sector public health co-benefits occur due to a change in physical features and characteristics of building structures. In COMBI, energy efficiency improvement actions are projected to take place in buildings of three functional uses: residential, tertiary and industrial. The work package (WP5) of the University of Manchester is limited to calculating co-benefits occurring as a result of energy efficiency investments in residential buildings only, as productivity impacts are studied separately by the project partner ABUD (WP5a). Most scientific literature focuses on co-benefits in the residential sector; tertiary buildings have been covered somewhat, especially through the sick building syndrome, whereas no studies have been found on co-benefits in industrial buildings. Productivity impacts from all types of buildings in COMBI are studied by ABUD employing a separate approach and methodologies (please refer to the COMBI report D5.4a).

In the transport sector, public health co-benefits occur due to a modal shift towards cycling and walking. Calculation of these impact end points has been abandoned due to limited COMBI timeline (but are partially studies in D5.4a). A few consultations have been held with the transport and health modellers at the Centre for Diet and Activity Research (CEDAR), University of Cambridge (owners of Integrated Transport and Health Impact Modelling Tool (ITHIM) and contributors to the WHOs Health Economic Assessment Tool (HEAT)). A conclusion carried from these meetings was that (1) COMBI data is insufficiently detailed to run ITHIM and (2) COMBI modal shift data is not sufficiently ambitious enough, the impacts would have been of marginal significance (as can be seen from D5.4a).

3.2 Impact pathways

As the COMBI social welfare literature review have established (D5.1, Mzavanadze et al., 2015), the evidence of the relationship between energy efficiency improvements and various aspects of social welfare is scattered and has not yet been systematically looked at. This may be one of the biggest theoretical and empirical contributions of COMBI project. Human health is probably the most important receptor of energy efficiency co-impacts. Figure 1 outlines impact pathways that link energy efficiency in buildings and public health outcomes due to various changes in the physical characteristics of the buildings.

Figure 1: Energy efficiency and human health impact pathways



Sources: (Braubach, Jacobs, Ormandy, World Health Organization, & Regional Office for Europe, 2011; Hänninen & Asikainen, 2013; Theakston & World Health Organization, 2011; WHO regional office for Europe, 2013; World Health Organization, 2009)

Due to limited timeline and resources, COMBI focused to quantify the co-impacts to public health related to energy poverty. Indoor cold and indoor dampness in residential housing are symptoms of energy poverty (Liddell & Morris, 2010). In total three co-impact categories have been proposed for evaluation in COMBI (see Figure 1):

- Excess winter mortality due to indoor cold;
- Excess winter morbidity due to indoor cold;
- Asthma morbidity due to indoor dampness.

Other co-impact categories are not operationalized enough (indoor air exchange and infectious respiratory diseases), pose major challenges in reconciling links with other methodologies (with WP3 air pollution methodology) or lack some essential baseline exposure indicators for estimating the burden of disease (e.g. lead, asbestos).

In the course of investigation due to unavailability of data it has also become clear that excess winter morbidity is not possible to quantify. Monthly data on hospitalizations, general practitioner visits or incidence of disease is not publically available. A proposed method based on annual morbidity data has not passed the internal review of COMBI scientific advisors. Therefore, the scope of this report becomes limited to two impact end-points:

- Excess winter mortality due to indoor cold;
- Asthma morbidity due to indoor dampness.

Other suggested non-health impact end points have been abandoned in favour of human health due to prioritization and limited timeline to perform such complex evaluations on EU-28 scale. Other initially proposed non-health impact end points included comfort, disposable income effect, national energy poverty projection. At least, energy cost savings in the residential sector may be regarded also as disposable income effect.

3.3 Definition of impacts, end-points and metrics/indicators

3.3.1 Thermal comfort and human health

In 2014, 10.2% of the EU population (around 50 million) were not able to keep their houses adequately warm during the winter season due to high heating costs and/or poor housing quality (Eurostat, 2016b). There are human health consequences arising as a result of inadequate thermal comfort indoors as defined by the World Health Organization (Braubach et al., 2011). The optimal indoor temperature is considered to be between 18-21 degrees Celsius and prolonged exposure to indoor cold below recommended temperatures can be associated with cardiovascular, respiratory diseases and poor mental health (Braubach et al., 2011; Gilbertson, Grimsley & Green, 2012; Howden-Chapman & Chapman, 2012). There is sufficient evidence that indoor cold is responsible for a share of these cases in mortality and morbidity, especially in the cold season (Braubach et al., 2011; Liddell & Morris, 2010). It has been noticed that coldest seasons provoke peaks in morbidity and mortality due to certain diseases. Suboptimal temperatures indoors may lead to prolonged cold exposure, and eventually, a rise in respiratory and cardiovascular diseases. More than two thirds of excess winter mortality cases are attributed to respiratory and cardiovascular diseases (Eurowinter Group, 1997; Mercer, 2003). Therefore, energy efficiency actions in residential housing are expected to contribute to improved health and increased life expectancy. It is assumed that better living conditions may even out or at least decrease the seasonal peaks of mortality and morbidity associated with wintertime.

Exposure to cold, indoors or outdoors, leads to acute (e.g., frostbites, hypothermia, death) and chronic physiological conditions related to respiratory and cardiovascular diseases under prolonged exposures (Hassi, 2005). Some of these chronic conditions may lead to excess winter deaths.

Mortality due to indoor cold is preceded by morbidity – cardiovascular and respiratory diseases. Numerous studies have confirmed a latent effect of temperature drop on the onset of illnesses, hospitalizations and general practitioner visits: they tend to be on increase with a delay in relation to a drop in outdoor temperature. For instance, in London a drop in average daily temperature by 1 degree C below 5 degrees C was found to be associated with a 10.5% increase in the onset of respiratory diseases and general practitioner consultations; and it was found to have up to 15 days lag (Hajat & Haines, 2002). But no such relationship was found for cardiovascular diseases very likely due to their chronic nature for general practitioner consultations, but the winter excess effect could be visible on acute symptoms - hospitalizations and deaths (ibid.). Indeed, lower temperatures were found to be related to an increased risk of hospitalisation due to cardiovascular diseases (Abrignani et al., 2009; Lan Chang, Shipley, Marmot, & Poulter, 2004; Martínez-Sellés et al., 2002; Stewart, McIntyre, Capewell, & McMurray, 2002).

Lowest mortality rates according to monthly data occur around a narrow range of average day outdoor temperatures of 15-25 degrees Celsius (Howden-Chapman, 2004). Excess winter morbidity and mortality cases capture the influence of many factors, such as air pollution, seasonal epidemics, suitability of outdoor clothing, poor quality housing; while comparisons between countries add another level of complexity due to socio-economic differences between countries in terms of economic development, education, health spending and health care systems, diets and obesity, lifestyles and behaviour (Clinch, 2000; Eurowinter Group, 1997; Healy, 2003; Mercer, 2003). In general, lack of pan-European studies on the health consequences of energy poverty is a complicating circumstance for such assessment endeavours as COMBI.

Relationship between mental health, energy poverty and indoor cold is insufficiently operationalized at this stage to be included in a national scale quantification of co-impacts. Mental health impairments due to housing quality may also be interlinked with noise exposure from outdoors, poor housing quality, e.g. draughts, leaks.

Table 1: Avoided excess winter deaths: definition & unit

Impact	Definition	Units
Avoided excess winter deaths	Human health improvements - reduced excess winter morbidity and mortality - arising from increased indoor thermal comfort	Number of deaths

during the cold season. Energy efficiency improvement actions in the residential housing sector related to building envelope insulation and heating system improvement or replacement indoor thermal comfort lead to indoor temperature increases to match the World Heath Organization thermal comfort guidelines for indoors (18-21 C)

3.4 Indoor dampness and human health

Energy efficiency improvement actions in residential housing may have implications for indoor dampness and associated diseases. Dampness leads to growth of indoor mould that can cause allergies and asthma. Around 13% of all dwellings in EU-28 are reported to have a dampness problem (Kolokotsa & Santamouris, 2015). Different age groups demonstrate different sensitivity and relative risk to dampness related asthma with children being the most sensitive (Braubach et al., 2011). Leaks, draughts, and poorly insulated outer walls can cause indoor cold and dampness – an environment suitable for mould growth. In general, insulation of building envelope and improvements in heating system help to eliminate the dampness problem along with increasing indoor temperatures and thermal comfort.

However the relationship between indoor dampness and envelope insulation is complex. Poor quality housing with leaks, draughts, poorly insulated walls is likely to benefit from shallow and medium insulation levels in eliminating the dampness problem. But as insulation level is increased the relationship maybe reversed – with increasing indoor air tightness, indoor humidity sources may not be dispersed well enough and may start to cause mould growth (Dimitroulopoulou, 2012). The relationship between housing insulation levels and indoor dampness may take a shape of letter U with an optimum situation around the middle – medium levels of insulation. Therefore, ensuring adequate ventilation is key in higher levels of insulation in order to avoid causing new cases of asthma in places where they may have not been before (Heseltine, Rosen, & World Health Organization, 2009).

Table 2: Avoided asthma – definition & unit

Impact	Definition	Units
Avoided asthma burden of disease attributable to indoor dampness	Human health improvements - reduced asthma morbidity – arising from decreased indoor dampness and increased thermal comfort as a result of energy efficiency improvement actions in the residential housing sector related to building envelope insulation and heating system improvement or replacement.	DALYs

3.5 EEI actions relevant for social welfare impact end-points

Table 3: Relevance of EEI actions to social welfare impacts.

#	End-use energy efficiency action	Considered in this work package
Action 1	residential refurbishment of the building shell + space heating + ventilation + space cooling (air-conditioning)	Yes. Sufficient evidence and operationalization in scientific literature on the implications to social welfare, human health, poverty reduction, comfort.
Action 2	residential new dwellings	Yes. Passive houses, nZEBs as state of the art buildings, are considered to be exemplary cases of buildings with maximum social welfare, well being and comfort attained. Other new buildings that comply with baseline regulation also are considered to improve well-being, comfort and health.
Action 3	residential lighting (all dwellings);	No. In principle there is a link, little evidence in the scientific literature, difficult to operationalize.
Action 4	residential cold appliances (all dwellings);	No. In principle there is a link, little evidence in the scientific literature, difficult to operationalize.
Action 5	non-residential refurbishment of building shell + space heating + ventilation + space cooling (air-conditioning)	No. Please refer to the COMBI report 5.4a
Action 6	non-residential new buildings	No. Please refer to the COMBI report 5.4a
Action 7	non-residential lighting (all buildings)	No. Please refer to the COMBI report 5.4a
Action 8	non-residential product cooling (all buildings)	No. Please refer to the COMBI report 5.4a
Action 9	passenger transport – modal shift	No. Sufficient evidence and operationalization in scientific literature on the implications to human health and well being. But omitted due to limited COMBI timeline and insufficiently ambitious modal shift scenario data. Impacts would have likely been marginal.
Action 10	passenger transport – motorized two-wheelers	No
Action 11	passenger transport – car	No
Action 12	passenger transport – bus	No
Action 13	freight transport – modal shift	No
Action 14	freight transport – light duty truck (LDT)	No
Action 15	freight transport – heavy duty truck (HDT)	No
Action 16	industry (7 sectors) - high temperature process heating	No
Action 17	industry (7 sectors) - low and medium temperature process heating	No
Action 18	industry (7 sectors) – process cooling	No
Action 19	industry (7 sectors) – specific process electricity	No
Action 20	industry (7 sectors) – motor drive	No
Action 21	industry (7 sectors) – HVAC in industrial buildings	No. Please refer to the COMBI report 5.4a

3.6 Distributional aspects

Both impact end-points quantified in this work package bear distributional implications for the society as a whole. Indoor cold and indoor dampness are symptoms of energy poverty – inability to afford necessary energy services, especially heating services during the cold periods of the year. The reasons that make heating energy services unaffordable are: poor housing quality (relatively high thermal conductivity of building envelope or its separate elements, poor insulation, draughts, disregarded maintenance needs); low income (whether short-term or longer-term state) and relatively high prices of energy services (in relation to household income) (S. Bouzarovski, 2014). Later on a few more reasons of energy poverty have been added in addition to affordability and energy efficiency: access and flexibility in relation to energy carriers as well as personal capabilities in relation to accessing necessary support or adapting one's housing and heating needs to changing personal circumstances (Stefan Bouzarovski & Petrova, 2015). In COMBI we only study energy efficiency keeping the rest of the factors constant.

The most socially vulnerable members of the society are likely to be affected by at least one or very often all root causes of energy poverty that lead to exposure to indoor cold and indoor dampness with negative consequences for health. Although these health conditions may not be limited to the socially vulnerable only, but they are mostly prevalent among the socially vulnerable (Liddell & Morris, 2010). Therefore, only energy efficiency policies in residential housing that specifically target the energy poor and socially vulnerable will bear the human health co-benefits in the form of reduced excess cold weather mortality and reduced asthma morbidity.

Energy efficiency investments in housing retrofits are one of the core policies to address energy poverty. However, very often the socially vulnerable members of the society do not have the financial resources and/or do not have the access to the necessary financial resources to proceed with housing retrofits not to mention other non-financial barriers. Unless the financial provisions of energy efficiency policies for residential housing specifically address the energy poor, there will neither be a major progress on energy poverty, nor on energy poverty-related health consequences such as excess cold weather mortality and asthma due to indoor dampness. Therefore, without financial provisions for targeting the socially vulnerable, there will be no gains in human health – co-benefits of energy efficiency are equal to null. To conclude, the human health co-benefits are to be maximized, if energy efficiency policies first target the energy poor.

COMBI input data does not specify where the financial resources come from and whether energy efficiency policies of the future have any special financial provisions for the energy poor, without which reaping of the human health co-benefits is likely to be impossible. To solve this problem, it is proposed to consider a few additional scenarios with respect to the energy efficiency policy outreach to the socially vulnerable (see chapter 5).

4 Methodology for impact quantification

4.1 Excess winter mortality

The number of excess winter mortality cases is calculated adding up the number of deaths occurring during the months that are universally agreed to represent winter in Europe (December, January, February and March) (actual deaths) and subtracting the total number of deaths occurring during the rest of months (April to November) divided by two (relation of expected deaths in 4 winter months vs. the remaining 8 months of the year) (see equation 1). Excess winter deaths index is calculated dividing the total number of excess winter deaths (equation 1) by the total number of deaths occurring during the rest of months (April to November) divided by two (expected deaths) (see equation 2).

$$\boldsymbol{EWD = \sum_{i=12}^{3} deaths - \sum_{i=4}^{11} deaths/2}$$ **Equation 1**

$$\boldsymbol{EWD_i = \frac{\sum_{i=12}^{3} deaths - \sum_{i=4}^{11} deaths/2}{\sum_{i=4}^{11} deaths/2} \times 100\%}$$ **Equation 2**

where EWD – excess winter deaths, EWD_i – excess winter death index, i – number of the month[1] (1 – January, 12- December) .

In countries of the EU, excess winter mortality rates ranged from 7.8% to 28.3% with an average of 13.9% in 2014 (Fowler et al., 2015). The estimates of southern and mild climate countries exceeded those of northern and continental countries which somewhat was attributed to better housing quality and better insulation in the latter ones (Clinch, 2000; Fowler et al., 2015; Healy, 2003). In the past the formula has been uniformly applied across the whole European continent with the same delineation between winter and non-winter months. The figure fluctuates from year to year depending on the severity of winters; therefore, an average excess winter deaths index is calculated for a certain period.

4.1.1 Attribution of excess winter deaths to indoor cold

Once the excess winter death rate is estimated, the key challenge is to attribute the part of excess winter mortality to, among many other factors, indoor cold, and therefore, poor quality housing. Excess winter deaths are attributable in general to an increase in exposure to air pollution due to heating demand in winter, exposure to indoor and outdoor cold, increase in winter-related infectious and bacterial epidemics as well as associate indoor crowdedness (Eurowinter Group, 1997). To this day there are no robust methodologies to estimate this ex-post or ex-ante. To complicate the matter, annual variations in severity of winter render different figures of EWDs and it is likely that the share of these attributed to poor quality housing also varies. Expert estimates have been used to date to attribute the number of excess winter deaths to indoor cold in poor quality housing (see Table 4).

[1] In this case the value of i in the formula is used in a non-traditional sense from 12 and on to 1,2,3 and from 4 to 11 representing the numeration of months.

Table 4. A review of expert estimates on the share of excess winter deaths attributable to indoor cold in poor quality housing.

Citation	Method	Country	% of EWDs attributed to poor quality housing
(Braubach et al., 2011)	Expert estimation: (1) J.D. Healy; (2) P. Wilkinson; (3) W.R. Keatinge	(1) Ireland, United Kingdom; (2) United Kingdom; (3) 7 European countries	(1) 33% (2) 30% (3) 50%.
(Tirado-Herrero, 2013)	Own estimation based on international expert estimates and available local sources on the circumstances of all cause deaths (e.g. number of cases of hypothermia)	Hungary	20%
(Hills, 2012)	Own estimation based on (University College, Marmot Review Team, & Friends of the Earth, 2011)	United Kingdom	10% (conservative estimate)
(University College et al., 2011)	Estimation based on (Wilkinson, 2001)	England	21,5%

As demonstrated in Table 4, only a few countries have expert estimates on the subject matter as energy poverty is still a rather new concept in the EU-28 context, mostly researched in the United Kingdom and Ireland. At this point, COMBI's evaluation of excess winter deaths attributable to indoor cold in poor quality housing for each country of the EU-28 poses major challenges due to absence of energy poverty studies and associated health expert evaluations.

At this point, a few solutions are possible with different implications for research time allocation:

- Select a universal and conservative rate, e.g. 10% of excess winter deaths, and apply uniformly across all countries;
- Perform desktop research on mortality, poverty, social deprivation in each country and come up with a customized estimates for each country based on (1) national public health data, such as a number of registered deaths due to hypothermia that was found to be related to energy poverty in Ireland (Romero-Ortuno, Tempany, Dennis, O'Riordan, & Silke, 2013) and/or (2) secondary data sources, such as the EU Survey on Income and Living Conditions (EU SILC) (Eurostat, 2016b);
- Engage public health experts of all countries in a consultation/survey.
- A mix of options above.

See Table 7 and related discussion in chapter 5.1 on how this issue has been resolved for the purposes of COMBI.

4.2 Excess cold weather mortality

Liddell et al., (2015) provide a methodological critique on the uniform application of the excess winter deaths formula (see equations 1 and 2) to European countries. Using heating degree days[2]

[2] One heating degree day stands for the average daily temperature outside being below the thermal comfort level by 1 degree C for 1 day. The heating threshold being 15 degrees C and the thermal comfort being 18

data, the authors point out that the indicator of excess winter deaths is accurately calculated according to the formula only for two European countries, where over 85% of heating degree days fall in the period between December and March. The figures for the rest of the countries may be underestimated or even severely underestimated as the cold weather period extends beyond the conventional four winter months as described before (or may be shorter). The paper suggests that adaptation of the cold weather period according to the actual national heating degree days (HDDs) data and recalculating the index of excess cold weather deaths may be necessary. The authors also point to large climatic differences even *within* countries and suggest a need of regional customization of the formula as well as a small change in the terminology – excess cold weather deaths instead of excess winter deaths. This critique also poses doubts, if the attribution of excess winter deaths to indoor cold has been accurate and if the previous estimates could be used as a guidance at all.

The approach taken for COMBI quantification purposes is to account for the recent methodological critique and re-calculate excess cold weather mortality customizing the cold weather period to include at least 85% of heat degree days for each EU member state (see chapter 4.1 and Table 6). Note the change in terminology – excess winter deaths (EWDs) are being replaced with excess cold weather deaths (ECWDs). The latter term will be used throughout the rest of the report.

4.3 Environmental burden of disease approach: asthma

The environmental burden of disease approach can be applied to assess the health implications of a change in indoor dampness exposure. Burden of disease refers to the prevalence of certain health conditions in the population in question and its implications (Pruss-Ustun, Mathers, Corvalan, & Woodward, 2003). “Environmental” refers not only to the environmental factors (e.g. air pollution), but in general to all factors that are external to human host in causing certain health impairments (e.g., work environments or poverty).

Box: Burden of disease approach

Burden of the disease approach was first developed in 1993 to respond to the needs of academics and decision-makers to have a complete and comparative view of the health status of the human population (World Health Organization (WHO), 2013). The first study was carried out by the Harvard School of Public Health and the World Health Organization. Today the Global Burden of Disease health monitoring project is lead by the Institute for Health Metrics and Evaluation at the University of Washington (http://www.healthdata.org) and is the most comprehensive study and database providing insights and data into mortality and morbidity across countries and regions since 1990. Read more on the inception, evolution and future challenges here - (Murray & Lopez, 2017).

degrees C (Eurostat 2017; Liddell, Morris, Thomson, & Guiney, 2015).

Global burden of disease reports provide the final results on the human health assessment in a society in a way that includes morbidity and mortality rates in one indicator called disability adjusted life years (DALYs) (ibid).

$$DALYs = YLLs + YLDs$$

where DALYs are disability adjusted life years,

YLLs – years of life lost and

YLDs – years lived with disability.

Years of life lost refer to the difference between the etalon of life expectancy (80 years for men and 82.5 for women) and the age at the time of death due to a certain cause. It is calculated as a sum of these differences.

$$YLLs = \sum N \times LE$$ (ibid.)

where N is the number of death cases and

LE is the life expectancy at the time of death.

Years lived with disability refer to the time in life that an individual has spent being not in perfect health.

$$YLDs = \sum I \times DW \times L$$ (ibid.)

where I is number of disability incidences, DW – disability weight, L – length of disability.

Many illnesses have more than one factor influencing its onset. For instance, the total disease burden of asthma in the society will be influenced by various factors: genetic factors, inhaled allergens (dust mites, animal fur, mould, pollen and etc.), inhaled irritants (tobacco smoke, cooking and heating fumes, vehicle exhaust, cosmetics, aerosols), medicines (aspirin); actions provoking asthma include respiratory infections, exercise, acute stress, tobacco smoke, consumption of certain foods, drinks or medicines, occupational exposures (Global Asthma Network, 2014).

It is possible to attribute the share of total disease burden in the society due to a certain health risk, e.g. exposure to mould in the case of asthma from the long list of factors. To enable this evaluation an attributable or relative risk value is needed from the epidemiology literature. Attributable/relative risk is a percentage difference in observed morbidity between the exposed and unexposed populations. Or in other words it is the share of the disease burden that would no longer occur if the risk factor were eliminated (Pruss-Ustun et al., 2003). This method has an inbuilt flaw of somewhat inflating the values of attributive risk, because assessments of this scale will not be able to fully control for other risk factors that may be causing the disease in question (Pruss-Ustun et al., 2003).

$$PAF = \frac{P \times (RR-1)}{P \times (RR-1)+1}$$ (Braubach et al., 2011)

where PAF is population attributable fraction, or the proportional share of responsibility born by the environmental risk factor in question in the total environmental disease burden,

P – proportion of population exposed,

RR - attributable or relative risk of disease onset under exposure.

As a consequence, the disease burden attributable to the environmental risk factor in question will be calculated as a share of the total disease burden:

$AEDB = PAF \times EDB$ (Braubach et al., 2011; Pruss-Ustun et al., 2003)

where AEDB is attributable environmental disease burden,

EDB – total environmental disease burden

and PAF – population attributable fraction.

The net health effect will depend on the difference between baseline PAF, reference scenario PAF and energy efficiency scenario PAF. The key variable, the value of which will change, will be p – proportion of population exposed.

The change in the disease burden attributable to environmental risks of housing as a result of energy efficiency improvement actions will essentially depend on (1) the distributional aspects of the tentative energy efficiency policy (social/poverty reduction policy scenarios); (2) the extent of housing stock profile changes in terms of quantity (demolished housing units versus new housing) and quality (levels of retrofits – shallow, medium and deep; types of new buildings built – standard, net zero energy buildings or passive houses); (3) the assigned mitigation potential rate to different housing types (expert score indicating the extent, to which housing quality changes may contribute to a decrease in certain exposures and consequently health conditions).

4.3.1 Indoor dampness, mould and the relative risk of asthma

Attributable/relative risk is a ratio in observed morbidity between the exposed and unexposed populations.

$$RR = \frac{Pe}{Pc}$$

where RR – relative risk,

Pe – probability of the disease emerging among the exposed to a particular risk factor;

Pc – probability of the disease emerging among the non-exposed to a particular risk factor.

It points to the share of the disease burden that could be avoided if the exposure were to be removed completely (Pruss-Ustun et al., 2003).

For attribution of asthma disease burden for children in the European region[3] the WHO study (Braubach et al., 2011) uses relative risk estimates of exposure to dampness (2.2, 95% CI: 1.3-4.0)

[3] Europe in this study means geographical Europe – 45 countries, not political Europe - EU-28.

and mould (2.4, 95% CI: 1.1-5.6) originating from two Finnish studies respectively – Pekkanen et al. (2007) and Jaakkola, Hwang, & Jaakkola (2004).

The same WHO study (Braubach et al., 2011) selects one exposure to dampness and one exposure to mould figure based on estimates in the scientific literature in different climatic zones. To sum up, the WHO study uses a conservative 15% central estimate of exposure to dampness and a conservative 5% estimate for exposure to mould in European dwellings (range of exposure to dampness in European countries is 10-25% and to mould – 5-25%). The burden of asthma on European children from 0-14 years old is reported as one overall figure for the region.

In COMBI, quantification of impact-end points is done on the EU member state level. This calls for exposure to dampness or mould estimates for each EU member state preferably originating from the same source. Dampness and mould in housing may be one of the signs of energy poverty. European Union Survey on Income and Living Conditions (EU SILC) (Eurostat, 2016b) is a popular reference point for the national energy poverty estimates. It provides various representative survey-based estimates on housing conditions, income, housing related bills. One of the EU SILC questions on housing conditions asks about the presence of "a leaking roof, damp walls, floors or foundation, or rot in window frames of floor" (indicator code: hlth_dhc070) (Eurostat, 2016b). The indicator is comprised of self-reported answers, not building specialist's inspection. This indicator can be used in COMBI as an exposure to dampness estimate in dwellings for EU member states.

In an ideal case, relative risk estimates for asthma onset in relation to exposure to dampness should be climate zone specific, for instance, Mediterranean Europe, North-Western Europe with high outdoor humidity throughout the year, Nordic Europe and Continental Europe.

There are a few articles that attempt to review and synthesize the results of indoor dampness/mould and asthma onset studies (Fisk, Lei-Gomez, & Mendell, 2007; Mendell, Mirer, Cheung, Tong, & Douwes, 2011; Quansah, Jaakkola, Hugg, Heikkinen, & Jaakkola, 2012). One of their challenges is to navigate different study methodologies (intervention studies, prospective studies, retrospective studies and cross-sectional studies) and assess to what extent the results are actually comparable. Asthma definitions differ in each study (such as self-reported asthma symptoms, like wheezing versus doctor diagnosed asthma and asthma medication intake) and correspondingly different exposure definitions (such as water damage, dampness, mould or mould odour, self-reported or inspected and confirmed by building specialists). Further important differences include age of participants (most studies observe children's morbidity), geographical location (asthma prevalence may vary as dampness exposure may also vary due to climate and also season). What remains unstudied is a multi-location exposure: Most studies investigate dampness in residential housing, while exposures in other indoor locations where people spend significant amounts of time remain unaccounted, such as schools, workplaces, kindergartens.

Of the three meta-analyses, only one distinguishes between different exposure definitions in assessing asthma onset due to various dampness related exposures – Quansah et al., 2012; the other two do not differentiate between different types of exposures (Fisk et al., 2007; Mendell et al., 2011) (see Table 5). Quansah et al. (2012) develop a causal pathway between different exposure definitions starting from water damage, followed by indoor dampness, later presence of visible mould and finally mould odour with an increasing risk of asthma at every step. However, Quansah et al. (2012) does not differentiate between different age groups, although majority of studies explore various mould related exposures to children. Fisk et al. (2007) state that there are still too few studies to enable meta-analysis for different age groups or gender. Neither of the studies emphasize geographical location factor. Mendell et all attempts to synthesize the literature for some exposures and health outcomes according to age groups, but relative risk estimates for asthma onset is provided only for the general population without age group distinction.

Table 5. A summary of meta analyses on relative risk of asthma development in relation to indoor dampness or mould.

Reference	Relative Risk and 95% Confidence Interval	Description of exposure	Number of studies
(Fisk et al., 2007)	1.34 (0.86-2.10)	Does not distinguish between dampness, mould, dampness or mould, and dampness and mould.	4
(Mendell et al., 2011)	Prospective studies – 0.65-7.08	Dampness or mould	6
	Retrospective studies 0.63-4.12		8
	Cross-sectional 1.6-2.2		3
(Quansah et al., 2012)	1.12 (0.98-1.27)	Water damage	8
	1.33 (1.12-1.56)	Dampness	9
	1.29 (1.04-1.6)	Visible mould	12
	1.73 (1.19-2.5)	Mould odour	8

To sum up, for COMBI, a relative risk estimate to dampness is required as the exposure estimate from the EU SILC includes a description of both – water damage and dampness, but not mould. There are no estimates available for different age groups for dampness and asthma onset from the available meta-analyses. Therefore, COMBI adopts a universal (referring to all population) relative risk estimate for asthma onset as a result of exposure to dampness for all age groups - 1.33 (95% Confidence interval: 1.12-1.56) (Quansah et al. 2012).

5 Quantification

5.1 Excess cold weather deaths

The COMBI project has gone one step further in re-defining the excess winter mortality problem. The proposal to re-name the phenomenon and customize the calculation of the index follows the ideas of Liddell et al., (2015). Excess winter deaths (EWDs) have been re-named into excess cold weather deaths (ECWDs). The cold weather period concept has been extended on a country-by-country basis to include at least 85% of the average annual heat degree days in a specific country. A comparison of the two methods can be seen below in Table 6.

Table 6: Comparison of excess winter mortality versus excess cold weather mortality: excess mortality index, share of heat degree days captured by the formula, and average annual number of deaths.

	EWDi (old formula) (1996-2014), %	Share of total average annual heat degree days captured, %	Annual average EWDs (1996-2014), number of cases	ECWDi (new customized formula) (1996-2014), %	Share of total average annual heat degree days captured, %	Annual average EWDs (1996-2014), number of cases
Austria	13.5%	61%	3292	10.8%	90%	4733
Belgium	15.2%	60%	5005	12.1%	89%	6826
Bulgaria	18.3%	70%	6424	16.8%	91%	8661
Croatia	14.3%	69%	2325	11.2%	96%	3120
Cyprus	19.2%	91%	316	19.2%	91%	316
Czech Rep.	10.3%	61%	3569	8.6%	90%	5126
Denmark	12.8%	57%	2300	9.9%	86%	3047
Estonia	11.7%	58%	642	10.4%	87%	980
Finland	10.1%	54%	1610	6.2%	94%	2197
France	14.6%	63%	25255	11.4%	92%	33912
Germany	11.5%	61%	31299	9.6%	90%	44642
Greece	11.8%	76%	4011	9.0%	96%	4566
Hungary	11.7%	69%	5016	10.6%	96%	7720
Ireland	16.8%	51%	1567	14.5%	87%	2597
Italy	16.6%	71%	30014	12.2%	97%	37931
Latvia	12.2%	59%	1229	13.8%	93%	2645
Lithuania	11.0%	60%	1474	11.8%	89%	2666
Luxembourg	13.1%	59%	158	9.6%	88%	197
Malta	30.6%	90%	287	30.6%	90%	287
Netherlands	12.1%	60%	5323	9.0%	89%	6861
Poland	11.0%	61%	13259	10.1%	90%	20792
Portugal	28.1%	71%	8979	23.1%	92%	10855
Romania	17.1%	68%	14043	17.7%	95%	24253
Slovakia	7.7%	64%	1310	6.6%	92%	1943
Slovenia	12.6%	66%	755	10.3%	94%	1060
Spain	20.4%	67%	23820	16.0%	90%	27706
Sweden	13.6%	53%	3981	9.4%	93%	5999
United Kingdom	17.0%	52%	31612	14.5%	88%	51836
Total EU-28			**228875**			**323475**

Sources: Eurostat 2017.

In most cases excess, the mortality index has slightly decreased with a few exceptions of Romania, Latvia, Lithuania, where excess mortality index has slightly increased (see Table 6). The values for Cyprus and Malta have remained the same as the winter period matches with the newly defined cold weather period – four months of December, January, February and March. The overall rate of the annual average heat degree day capture by the customized formula of excess cold weather deaths has increased. As a result the absolute values of excess mortality due to seasonality have increased (see Figure Table 6). In total average excess cold weather mortality in the EU-28 accounts for 323 475 number of deaths annualy. In general, the excess cold weather deaths index seems to be smaller in Nordic countries and a few Central European Countries.

Although this approach and the revised figures still have not gone through the official peer review process, COMBI project advisors suggested to proceed with the customized cold weather period formula.

Excess cold weather mortality is thought to be associated with physical exposure to cold indoors and outdoors, a rise in air pollution due to a surge in heating activities, a rise in infectious diseases during the cold season (Eurowinter Group, 1997), effectiveness and preparedness of the health care systems in mitigating these temporary peaks. Attribution of the share of the excess cold weather deaths to indoor cold has been discussed in chapter 4.1.1, see Table 4. The state of the public health research on indoor cold exposure in different EU member states and its role in excess cold weather mortality is inadequate and credible estimates are available only for a handful of countries. The expert estimates range from 10% to 50% and they are available only for a handful of countries. The WHO suggests a universal 30% attribution rate to indoor cold for the region of Europe as a whole (Braubach et al., 2011).

Nevertheless, it does not seem to be justifiable to apply a universal indoor cold attribution rate to excess cold weather deaths to countries that have a good record of developed social welfare system and good thermal comfort standards of residential buildings, and on the other hand, to the others that lack one or both elements. The EU SILC survey provides some insight in how prevalent indoor cold may be among the populations of the EU-28. One of the indicators is "share of the population unable to keep home adequately warm" (Eurostat, 2016b). In relation to this, the logic of attribution rate would be this: the bigger share of the society is exposed to indoor cold, the bigger is the contribution of indoor cold to excess cold weather deaths. Prevalence of indoor cold among the populations of the EU-28 ranges between 0.9% in Luxembourg to 39.2% in Bulgaria in 2015 (Eurostat, 2016b). Or in other words, 0.9% of survey respondents in Luxembourg answered that they were unable to keep their home adequately warm, while 39.2% stated the same in Bulgaria (see Table 23 in the Annexes chapter 8).

There are two possible solutions in relation to attribution of excess cold weather deaths to indoor cold:

- Apply a universal 30% attribution rate to all EU-28 as suggested by the WHO;
- Apply a customized rate depending on EU SILC indoor cold exposure indicator.

In order to account not only for differences in the actual number of excess cold weather deaths, but also for the differences in prevalence of indoor cold among the European Union member states, it is suggested to apply the second approach for indoor cold attribution. It is proposed to tie the attribution to indoor cold estimate to the EU SILC indicator on the percentage share of the society unable to keep homes adequately warm (see Table 7).

A minimal attribution rate of 10% is suggested for countries that manifest relatively small rates of thermal discomfort between 2010 and 2015 – on average 5% or less of the country's population have reported to be unable to afford to keep their home adequately warm. Countries falling under this category are Denmark, Germany, Estonia, Luxembourg, Netherlands, Austria, Finland, Sweden.

The second tier – countries where on average between 5% and 10% of the population report inability to keep their homes adequately warm in 2010-2015. In this case, 20% attribution rate of excess cold weather deaths will be attributed to indoor cold. Countries in the second tier include Belgium, Croatia, Czech Republic, France, Ireland, Slovak Republic, Slovenia, Spain and United Kingdom.

The third tier countries are those where material deprivation to secure adequate thermal comfort exceeded an average of 10% of the population between 2010 and 2015. For this case, a 30% attribution rate will be applied. The countries in this tier include Bulgaria, Cyprus, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal and Romania (see Table 23 in the Annexes).

Table 7 provides a summary of the suggested proxies for attribution rates of excess cold weather deaths to indoor cold. Compared to the WHO-proposed 30% flat rate attribution, this is thus a conservative estimate.

Table 7: Suggested proxies for attribution of excess cold weather deaths to indoor cold

Share of population unable to keep home adequately warm (EU SILC), average in 2010-2015	Share of ECWDs attributable to indoor cold
x<5%	10%
5%<x<10%	20%
x>10%	30%

This enables us to establish the extent of problem in different EU member states at the base year – 2015 (see Table 8). The total average annual excess cold weather deaths figure for the EU-28 is 323 475 (CI 95%: [103377- 543573]). Out of those, 69 899 of death cases (CI 95%: [22358-117439] can be attributed to exposure to indoor cold and they are subject to energy efficiency co-benefits. Assuming all housing stock would be retrofitted and energy poverty conditions eradicated, all other factors staying ceteris paribus, 69 899 cases of premature deaths could be avoided annually in the EU-28. It will be assumed that this figure of annual excess cold weather deaths due to indoor cold is constant throughout the studied period.

The extent of residential building renovation activities as well as new construction activities and their quality (energy efficiency level of retrofits and new buildings) are the key factors in modeling excess mortality co-benefits. COMBI input data (D2.3) defines the profile of the national housing stocks in 2015 (base year), and 2030 under reference and efficiency scenarios (see Table 24, Table 25 and Table 26). The housing stock is divided into seven categories and their technical parameters are given as part of COMBI input data (the width of insulation added; the types of windows installed and etc.):

- surviving non-retrofitted buildings;
- shallow retrofits
- medium retrofits
- deep retrofits
- new base standard buildings
- net zero energy buildings
- passive houses.

The types of buildings and their share have been matched with their potential to deliver an associated health co-benefit; in this case – avoided premature deaths due to indoor cold exposure. Unavoidably another set of assumptions had to be taken to proceed with quantification of co-benefits, as scientific literature does not offer any examples of such long-term observation-al public health studies that would link improvements in housing to mortality reductions or life expectancy increases. The set of assumptions is presented in along with a brief explanation on the score given (see Table 9). These scores have gone through an internal COMBI advisory board review.

Table 8: Attribution of excess cold weather deaths to indoor cold

	Average ECWDi, lower bound CI=95%	Average ECWDi (1996-2014)	Average ECWDi, upper bound CI=95%	Average annual ECWDs, number of cases CI=95%, lower bound	Average annual ECWDs (1996-2014), number of cases	Average annual ECWDs, number of cases CI=95%, upper bound	Share of population unable to keep home adequately warm (EU SILC), average in 2010-2015	Share of ECWDs attributable to indoor cold	Lower bound CI-95% (Average annual ECWDs attributable to indoor cold, number of cases)	Average annual ECWDs attributa-ble to indoor cold, number of cases	Upper bound CI-95% (Average annual ECWDs attributable to indoor cold, number of cases)
Austria	2.1%	10.8%	19.6%	1337	4733	8129	3.0%	10%	134	473	813
Belgium	5.0%	12.1%	19.1%	2998	6826	10653	6.0%	20%	600	1365	2131
Bulgaria	6.4%	16.8%	27.2%	3318	8661	14005	47.3%	30%	995	2598	4201
Croatia	1.6%	11.2%	20.7%	583	3120	5657	9.6%	20%	117	624	1131
Cyprus	5.7%	19.2%	32.8%	87	316	546	28.5%	30%	26	95	164
Czech Rep.	2.8%	8.6%	14.3%	1674	5126	8578	5.9%	20%	335	1025	1716
Denmark	2.6%	9.9%	17.2%	844	3047	5250	2.8%	10%	84	305	525
Estonia	2.8%	10.4%	18.0%	268	980	1691	2.8%	10%	27	98	169
Finland	0.9%	6.2%	11.6%	319	2197	4075	1.5%	10%	32	220	408
France	3.5%	11.4%	19.4%	10815	33912	57008	6.0%	20%	2163	6782	11402
Germany	2.5%	9.6%	16.6%	12003	44642	77282	4.9%	10%	1200	4464	7728
Greece	0.0%	9.0%	18.0%	192	4566	8940	25.3%	30%	58	1370	2682
Hungary	2.8%	10.6%	18.3%	2029	7720	13410	12.3%	30%	609	2316	4023
Ireland	7.5%	14.5%	21.5%	1234	2597	3961	8.3%	20%	247	519	792
Italy	2.7%	12.2%	21.7%	10668	37931	65194	17.4%	30%	3201	11379	19558
Latvia	5.8%	13.8%	21.8%	1162	2645	4127	19.0%	30%	349	793	1238
Lithuania	3.8%	11.8%	19.8%	976	2666	4356	30.4%	30%	293	800	1307
Luxembourg	-1.1%	9.6%	20.3%	-17	197	411	0.9%	10%	-2	20	41

Malta	9.7%	30.6%	51.4%	99	287	475	18.9%	30%	30	86	143
Netherlands	2.9%	9.0%	15.1%	2364	6861	11359	2.4%	10%	236	686	1136
Poland	1.6%	10.1%	18.6%	3663	20792	37920	11.6%	30%	1099	6238	11376
Portugal	7.2%	23.1%	39.1%	3801	10855	17909	27.3%	30%	1140	3257	5373
Romania	7.1%	17.7%	28.3%	10297	24253	38210	15.2%	30%	3089	7276	11463
Slovakia	-0.8%	6.6%	14.0%	-159	1943	4044	5.3%	20%	-32	389	809
Slovenia	1.9%	10.3%	18.7%	221	1060	1900	5.4%	20%	44	212	380
Spain	2.9%	16.0%	29.1%	6019	27706	49393	8.8%	20%	1204	5541	9879
Sweden	3.4%	9.4%	15.3%	2351	5999	9647	1.3%	10%	235	600	965
United Kingdom	6.7%	14.5%	22.2%	24230	51836	79443	8.1%	20%	4846	10367	15889
Total EU-28				**103377**	**323475**	**543573**			**22358**	**69899**	**117439**

Data sources: Eurostat 2017, own calculations.

Table 9: Excess cold weather mortality reduction potential in relation to housing quality: assumptions

	Excess cold weather mortality reduction potential	Assumptions
Light retrofits	50%	According to technical specification COMBI light retrofits are quite comprehensive and possibly represent medium retrofits in reality, but they may not be enough to make energy services affordable for the socially vulnerable, therefore a cautious 50% rating is given.
Medium retrofits	80%	An intermediary value is given in between light and deep retrofits.
Deep retrofits	100%	Deep retrofitted buildings are assumed to maximize thermal comfort indoors and are assumed to perform just as well as the new state of the art buildings.
New buildings - base standard	80%	New base standard buildings on average are considered to be better in securing indoor thermal comfort than the existing housing stock, but they are still assumed to be inferior to deep retrofits or state of the art new buildings. As the European Union establishes a mandatory nZEB or passive house standard, this category ceases to expand in the future COMBI scenarios.
Net zero energy buildings (nZEBs)	100%	These buildings represent the state of the art of residential buildings design and technology, they are assumed to maximize the well-being and all housing related health aspects, including indoor cold related health consequences.
Passive houses	100%	These buildings represent the state of the art of residential buildings design and technology, they are assumed to maximize the well-being and all housing related health aspects, including indoor cold related health consequences.
Surviving non-retrofitted buildings	0%	These buildings do not undergo any retrofits between 2015 and 2030, nor have been retrofitted before 2015. Change in health co-benefits is expected only as a result of the change in housing characteristics.

Because indoor cold is a phenomenon that affects the socially vulnerable and energy poor members of the society, the human health co-benefits as a result of energy efficiency investments of the society will only take place if energy efficiency policies target specifically this group of the society in the EU as a whole and separately at the member state level. As it has been noted before, COMBI input data does not give any indication to what extent projected energy efficiency investments in residential housing reach the socially vulnerable and energy poor (see chapter 3.6). The COMBI input data also does not specify the sources of the financial flows towards energy efficiency investments (public or private or both). Therefore, it has been necessary to show the importance of social cohesion and poverty eradication policies in reaping off the human health co-benefits on the level of the society as a whole.

Three scenarios with regard to the extent of energy efficiency policies reaching the energy poor and socially vulnerable have been proposed (see below). All of them unavoidably imply about the involvement of public funding, full or partial subsidies or other preferential financial mechanisms that at least to some extent dismantle the financial and other non-cost barriers in the adoption energy efficiency measures among the socially vulnerable.

Three scenarios have been proposed to illustrate the impact of social policies on the public health impacts of energy efficiency improvement actions:

- **No emphasis on social policy scenario**. This scenario takes into account the likelihood of the energy efficiency investments reaching the socially vulnerable. For instance, how likely are the socially vulnerable to dwell in new state of the art buildings – like passive houses or nZEBs? It is assumed that the share of the socially vulnerable affected by energy efficiency policies is proportional to the sum of the shares of shallow retrofits, medium retrofits and new base standard buildings.

- **Prioritizing the socially vulnerable**. This scenario is a mid-way scenario between the other two – socially vulnerable are prioritized to a higher degree than the "no emphasis on social policy scenario", but is more realistic in terms of the scope of the policy outreach to the socially vulnerable. It is assumed that the share of the socially vulnerable affected by energy efficiency policies is proportional to the sum of the shares of shallow retrofits, medium retrofits, deep retrofits and all new buildings.
- **Socially vulnerable first**. This scenario is the most unlikely from the financial and practical point of view and assumes that energy efficiency policies in the residential housing sector reach the socially vulnerable first. This way the value of the human health co-benefits is maximized. *De facto* operationalizing such a societal goal into a policy would be quite problematic for multiple reasons: (1) identification and targeting the energy poor is problematic due to the dynamics of the energy poverty factors; (2) for multi-apartment buildings it would not be practical to renovate just patches of a building; (3) the likelihood of raising such significant financial sums for subsidies or for other kinds of preferential financial mechanisms.

For the purposes of COMBI main conclusions and outreach it is suggested to quote the results of COMBI reference "no emphasis on social policy" scenario with the COMBI efficiency "prioritizing the socially vulnerable" scenario. These two scenarios represent a minimum and a maximum extent of public health co-impacts as a result of COMBI retrofit scenarios and a range of possibilities in between. A summary comparison between the scenarios and scenarios combinations (extent of retrofit and social policy) is presented in Table 10. More details on COMBI reference and efficiency scenarios for residential housing retrofits can be found in the chapter 8 – Annexes. In depth information on COMBI residential housing retrofits can be found in COMBI D2.2 report on the scope of COMBI, EEI actions and scenarios (see also D2.2 annex). The main results of this report will be highlighted in light green in the tables below.

Table 10 . Comparison of key factors in COMBI scenarios

COMBI retrofit scenarios (↓) versus social policy scenarios (→)	"No emphasis on social policy"	"Prioritizing the socially vulnerable"
Reference	Lower extent of residential housing retrofits+lower depth of retrofits[4]+no social policy towards socially vulnerable	Lower extent of residential housing retrofits+lower depth of retrofits+strong social policy towards socially vulnerable
Efficiency	Higher extent of residential housing retrofits+higher depth of retrofits+no social policy towards socially vulnerable	Higher extent of residential housing retrofits+higher depth of retrofits+ strong social policy towards socially vulnerable

Assuming constant annual excess cold weather deaths ceteris paribus (see Table 8), the mitigation potential of this phenomenon takes different paths depending on the social orientation of the energy efficiency policies (see Table 11)

[4] Retrofit depth refers to the level of insulation: the higher the depth of retrofit the bigger is the insulation level and the lower is the heat loss.

Under the "socially vulnerable first" scenario, if the society could divert all of the financial resources previewed in COMBI targeting the socially vulnerable first, excess cold weather mortality due to indoor cold as a phenomenon could be eradicated in most EU member states with the exception of Bulgaria only – around 70 000 premature deaths annually. This conclusion has been made comparing the extent of the indoor cold prevalence in 2015 (EU SILC estimate on the share of population unable to heat their homes adequately) (see Table 8) with the scope of the energy efficiency interventions previewed in the two scenarios of COMBI.

Table 11. Excess cold weather mortality reduction potential in relation to social policies for COMBI Reference and Efficiency scenarios in 2030.

	Scenario "No emphasis on social policy": Mitigation potential of ECWD in 2030, %		Scenario "Prioritizing socially vulnerable": Mitigation potential of ECWD in 2030, %		Scenario "Socially vulnerable first": Mitigation potential of ECWD in 2030, %	
	Reference	Efficiency	Reference	Efficiency	Reference	Efficiency
Austria	4%	8%	26%	36%	100%	100%
Belgium	5%	10%	33%	41%	100%	100%
Bulgaria	4%	9%	34%	41%	73%	86%
Croatia	5%	8%	43%	50%	100%	100%
Cyprus	5%	8%	42%	49%	100%	100%
Czech Rep.	6%	12%	25%	34%	100%	100%
Denmark	5%	11%	34%	42%	100%	100%
Estonia	5%	11%	24%	33%	100%	100%
Finland	5%	11%	24%	33%	100%	100%
France	5%	11%	23%	31%	100%	100%
Germany	5%	11%	26%	35%	100%	100%
Greece	3%	6%	49%	56%	100%	100%
Hungary	2%	4%	53%	59%	100%	100%
Ireland	6%	11%	29%	37%	100%	100%
Italy	5%	9%	25%	34%	100%	100%
Latvia	3%	7%	55%	60%	100%	100%
Lithuania	4%	8%	54%	61%	100%	100%
Luxembourg	4%	8%	42%	48%	100%	100%
Malta	5%	10%	25%	33%	100%	100%
Netherlands	6%	12%	25%	34%	100%	100%
Poland	5%	11%	25%	34%	100%	100%
Portugal	4%	9%	36%	43%	100%	100%
Romania	3%	7%	34%	43%	100%	100%
Slovakia	6%	13%	29%	38%	100%	100%
Slovenia	4%	8%	29%	37%	100%	100%
Spain	4%	8%	44%	50%	100%	100%
Sweden	4%	9%	23%	32%	100%	100%
United Kingdom	6%	11%	28%	37%	100%	100%

The share and number of premature deaths avoided under the three scenarios can be found in Table 11 and Table 12. The last column of Table 12 represents the total burden of disease in 2015 and also the “socially vulnerable first” scenario. Overall, 31% (or around 22 000) of the 70 000 premature deaths happening annually due to indoor cold exposure could be avoided in 2030 in the EU-28 as a result of the COMBI reference scenario with social priorities (“prioritizing socially vulnerable” scenario) under the COMBI reference scenario. Under the COMBI efficiency scenario with social priorities 39% of premature deaths (around 27 500) could be avoided.

Under “no emphasis on social policy” scenario, only 5% (or over 3000) of premature deaths could be avoided in combination with the COMBI reference scenario in 2030 in the EU-28. Under the COMBI efficiency scenario around 10% (or over 6600) of premature deaths could be avoided (see Table 12).

Overall, the difference in the number of premature deaths avoided between the minimum impact scenario and the maximum impact scenario is significant. Only 5% or over 3000 of premature deaths due to indoor cold would be avoided in 2030 under the COMBI reference “no emphasis on social policy” scenario; while 39% or 27 500 premature deaths due to indoor cold exposure could be avoided under the COMBI efficiency “prioritizing socially vulnerable” scenario (see Table 12; highlighted in light green). The co-benefits of additional energy efficiency improvement actions coupled with strong social policies in 2030 could amount to around 24 500 avoided premature deaths in the EU-28.

Table 12: Avoided premature mortality due to exposure to indoor cold in EU-28 in 2030 under Reference and Efficiency scenarios and different levels of social policy sensitivity

	Scenario "No emphasis on social policy": Avoided ECWDs in 2030, number of cases		Scenario "Prioritizing socially the vulnerable": Avoided ECWDs in 2030, number of cases		Average annual ECWDs in 2015, number of cases
	Reference	Efficiency	Reference	Efficiency	
Austria	17	37	124	168	473
Belgium	72	143	456	563	1365
Bulgaria	102	233	891	1053	2598
Croatia	28	52	271	315	624
Cyprus	4	8	40	46	95
Czech Rep.	60	127	260	352	1025
Denmark	16	32	104	127	305
Estonia	5	11	23	32	98
Finland	11	23	52	72	220
France	345	743	1535	2133	6782
Germany	231	493	1178	1555	4464
Greece	41	87	677	764	1370
Hungary	46	99	1218	1375	2316
Ireland	30	60	151	194	519
Italy	513	1077	2816	3864	11379
Latvia	27	55	433	479	793
Lithuania	34	64	436	484	800
Luxembourg	1	2	8	9	20
Malta	4	9	22	28	86
Netherlands	38	79	174	232	686
Poland	323	682	1584	2100	6238
Portugal	136	294	1169	1408	3257
Romania	236	478	2449	3157	7276
Slovakia	24	49	113	148	389
Slovenia	8	18	61	79	212
Spain	200	435	2415	2768	5541
Sweden	26	56	141	190	600
United Kingdom	579	1174	2901	3797	10367
Total EU-28	3156	6620	21702	27496	69899

5.2 Asthma due to indoor dampness

To begin with, burden of disease of asthma due to indoor dampness is estimated at the base year – in 2015. The EU SILC indicator "share of total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames of floor" has been used as exposure indicator. Using the population-attributable fraction, a share of burden of disease of asthma attributable to indoor dampness has been estimated for all member states. All in all in 2015, asthma due to indoor dampness has been responsible for 71 652 DALYs in the EU-28 (CI: [18187-161 730]) (see Table 13). According to disability weights (Global Health Data Exchange (GHDx), 2017) this figure is an equivalent to 2 million cases of partially controlled asthma. It will be assumed that without any intervention the annual burden of disease of asthma due to dampness in the European Union member states would be constant throughout the studied period. The only parameter that is subject to change is prevalence of indoor dampness due to energy efficiency interventions.

Table 13: Burden of disease of asthma due to indoor dampness in the EU-28 in 2015

	Average exposure to dampness (2012-2014), % of total population	Lower bound (CI:95%)	PAF, %	Upper bound (CI:95%)	Lower bound (CI:95%)	Asthma burden of disease attributable to indoor dampness	Upper bound (CI:95%)
Austria	11.4	1.35	3.64	6.02	227	919	2098
Belgium	18.1	2.13	5.64	9.20	423	1634	3638
Bulgaria	13.3	1.57	4.20	6.93	138	546	1238
Croatia	12.7	1.50	4.02	6.64	88	337	761
Cyprus	28.9	3.35	8.70	13.92	80	298	648
Czech Republic	9.9	1.17	3.16	5.25	129	505	1135
Denmark	16.4	1.93	5.13	8.41	203	801	1814
Estonia	17.6	2.07	5.49	8.97	50	188	411
Finland	5.4	0.64	1.75	2.94	91	372	853
France	13.0	1.54	4.11	6.79	2087	8278	18946
Germany	13.0	1.53	4.10	6.77	2371	9223	20761
Greece	14.1	1.67	4.46	7.33	291	1179	2670
Hungary	26.1	3.04	7.93	12.75	359	1352	2920
Ireland	13.9	1.64	4.40	7.24	197	792	1837
Italy	23.1	2.70	7.08	11.45	1935	7676	17235
Latvia	27.8	3.23	8.40	13.47	119	447	963
Lithuania	18.8	2.21	5.84	9.53	96	374	828
Luxembourg	15.8	1.86	4.96	8.13	27	108	244
Malta	11.2	1.33	3.56	5.90	13	52	119
Netherlands	15.9	1.87	4.98	8.16	649	2640	6035
Poland	9.9	1.18	3.17	5.27	697	2738	6202
Portugal	28.9	3.35	8.71	13.93	869	3390	7501
Romania	14.4	1.69	4.53	7.45	475	1852	4130
Slovakia	7.8	0.92	2.50	4.17	56	223	503
Slovenia	29.5	3.42	8.86	14.16	69	265	568
Spain	15.3	1.80	4.80	7.88	1872	7348	16481
Sweden	7.6	0.90	2.44	4.07	162	649	1498
United Kingdom	16.6	1.95	5.18	8.49	4412	17467	39692
EU-28 total					**18187**	**71652**	**161730**

Sources: (Eurostat, 2016b; Global Health Data Exchange (GHDx), 2017).

Similarly as in the case of the excess cold weather deaths, modelling of asthma co-benefits rests on the COMBI input data on the profile of the housing stock (see Table 24, Table 25 and Table 26) and assigned reduction potential scores to the different types of housing. Just as in the case of premature mortality due to indoor cold, the scientific literature does not provide any estimates for attribution that could be used, therefore relying on expert estimates (COMBI advisory board) is proposed. The reason is that there are no long-term studies that would link housing renovation, or housing improvements to asthma morbidity. The estimates from single community observational or control studies are difficult to extrapolate to national scale. The scarcity of such studies is another reason. Therefore, the assumptions around housing renovation and asthma morbidity are transparently provided in Table 14.

Table 14: Asthma morbidity reduction potential: assumptions

Excess cold weather mortality reduction potential		Assumptions
Light retrofits	40%	Light retrofits may not be sufficient to solve the problem of indoor dampness for certain building types in certain climatic zones. On the other hand, usually light retrofits are not accompanied by ventilation solutions and there may be a risk of creating a problem of indoor dampness. Therefore, a cautious rate is given.
Medium retrofits	60%	Medium retrofits are given a higher rate due to their bigger likelihood to ensure adequate indoor humidity levels in poor state residential buildings and a bigger likelihood of including adequate ventilation solution in retrofit projects.
Deep retrofits	80%	Deep retrofits are all assumed to come with ventilation solutions. However, the building structure in this case is already given and may not be alterable (orientation of windows, the plan of the dwelling and division into rooms). Also with increasing insulation comes a higher risk of increasing indoor tightness and therefore, inadequate ventilation. Indoor dampness problem may appear in places where it has not been recorded before retrofits. Therefore, a cautious rate is given.
New buildings - base standard	70%	New base standard buildings on average are assumed to be better in securing appropriate indoor humidity levels and indoor air exchange than the existing housing stock, but they are still assumed to be inferior to the state of the art new buildings and deep retrofits. As the European Union establishes a mandatory nZEB or passive house standard, this category ceases to expand in the future COMBI scenarios (see Table 24, Table 25 and Table 26).
Net zero energy buildings (nZEBs)	100%	These buildings represent the state of the art of residential buildings design and technology, they are assumed to maximize the well-being and all housing related health aspects, including asthma due to dampness.
Passive houses	100%	These buildings represent the state of the art of residential buildings design and technology, they are assumed to maximize the well-being and all housing related health aspects, including asthma due to dampness.
Surviving non-retrofitted buildings	0%	These buildings do not undergo any retrofits between 2015 and 2030, nor have been retrofitted before 2015. Change in health co-benefits is expected only as a result of the change in housing characteristics.

Just as in the case of excess cold weather deaths, additional scenarios with regard to social policy are applied to illustrate how different the outcomes my be depending on the extent of the social policy. Indoor cold and indoor dampness often go hand in hand as a result of poor housing or due to the neglect of maintenance needs. The same social policy scenarios have been applied and they can be consulted in chapter 5.1. If all financial resources previewed under COMBI scenarios (either reference, or efficiency) could be diverted to the socially vulnerable first, in most member states indoor dampness would cease to be the cause of asthma. This conclusion has been made comparing the extent of energy efficiency interventions into the residential housing stock and the prevalence of indoor dampness among the populations of the EU-28 member states (Table 13). The only exceptions are Italy and Slovenia, where exposure of indoor dampness in 2015 was higher than the projected extent of energy efficiency policy outreach into the national building stock (see Table 15).

Table 15. Asthma due to indoor dampness reduction potential in relation to social policies for COMBI Reference and Efficiency scenarios in 2030

	Scenario "No emphasis on social policy": Mitigation potential of asthma burden of disease due to dampness in 2030, %		Scenario "Prioritizing socially vulnerable": Mitigation potential of asthma burden of disease due to dampness in 2030, %		Scenario "Socially vulnerable first": Mitigation potential of asthma burden of disease due to dampness in 2030, %	
	Reference	Efficiency	Reference	Efficiency	Reference	Efficiency
Austria	2.85%	6.02%	24.33%	31.76%	100%	100%
Belgium	4.11%	8.11%	31.80%	37.91%	100%	100%
Bulgaria	2.99%	6.94%	33.07%	37.98%	100%	100%
Croatia	3.64%	6.54%	41.94%	47.43%	100%	100%
Cyprus	3.62%	6.53%	40.43%	45.93%	100%	100%
Czech Rep.	4.49%	9.45%	23.53%	30.45%	100%	100%
Denmark	4.13%	8.16%	32.58%	38.44%	100%	100%
Estonia	4.12%	8.64%	21.68%	29.14%	100%	100%
Finland	3.90%	8.17%	21.99%	29.05%	100%	100%
France	3.88%	8.39%	20.86%	27.74%	100%	100%
Germany	3.97%	8.49%	24.70%	31.27%	100%	100%
Greece	2.30%	4.90%	48.27%	53.20%	100%	100%
Hungary	1.51%	3.26%	51.43%	56.74%	100%	100%
Ireland	4.44%	8.90%	27.28%	33.76%	100%	100%
Italy	3.49%	7.30%	22.94%	30.15%	97%	100%
Latvia	2.62%	5.39%	53.45%	58.00%	100%	100%
Lithuania	3.38%	6.24%	53.22%	57.92%	100%	100%
Luxembourg	3.13%	6.45%	40.46%	45.28%	100%	100%
Malta	3.87%	8.02%	23.39%	29.70%	100%	100%
Netherlands	4.30%	8.88%	23.55%	30.21%	100%	100%
Poland	3.98%	8.41%	23.72%	30.17%	100%	100%
Portugal	3.22%	6.99%	34.47%	40.20%	100%	100%
Romania	2.50%	5.02%	31.84%	39.49%	100%	100%
Slovakia	4.73%	9.64%	27.34%	34.18%	100%	100%
Slovenia	2.93%	6.42%	27.25%	33.85%	91%	100%
Spain	2.79%	6.07%	42.35%	47.35%	100%	100%
Sweden	3.26%	7.15%	21.81%	28.23%	100%	100%
United Kingdom	4.34%	8.75%	26.20%	32.92%	100%	100%

The asthma disease burden avoided under the three scenarios can be found in Table 16. The last column represents both – the disease burden at the baseline as well as the "socially vulnerable first" scenario. The public health outcomes of energy efficiency improvement actions in the residential housing sector range depending on the social policy scenarios outlined in chapter 5.1. Overall, under the "prioritizing socially vulnerable" scenario 28% (or 20 420 DALYs) of asthma burden of disease happening annually due to indoor dampness exposure could be avoided by 2030 in the EU-28 as a result of energy efficiency policies under the COMBI reference scenario. Under efficiency scenario 35% of asthma burden of disease (or 25 033 DALYs) could be avoided (see Table 16).

Under "no emphasis on social policy" scenario, only 4% (or 2 659 DALYs) of asthma morbidity burden could be avoided under the COMBI reference scenario in 2030 in the EU-28. For the COMBI efficiency scenario around 8% (or 5 550 DALYs) of asthma morbidity burden could be avoided (see Table 16).

To sum up, the public health impacts range from a minimum of 4% or around 2 659 DALYs reduction in asthma morbidity in 2030 under the "no emphasis on social policy" reference scenario to a maximum of 35% or 25 033 DALYs reduction in asthma morbidity under the "prioritizing socially vulnerable" efficiency scenario (see Table 16; highlighted in light green).

Table 16: Avoided asthma morbidity due to exposure to indoor dampness in 2030 compared to morbidity in 2015

	Scenario "No emphasis on social policy": Avoided asthma burden of disease due to dampness in 2030, DALYs		Scenario "Prioritizing socially vulnerable": Avoided asthma burden of disease due to dampness in 2030, DALYs		Asthma burden of disease due to indoor dampness in 2015, DALYs
	Reference	Efficiency	Reference	Efficiency	
Austria	26	55	224	292	919
Belgium	67	133	520	619	1634
Bulgaria	16	38	181	207	546
Croatia	12	22	141	160	337
Cyprus	11	19	121	137	298
Czech Rep.	23	48	119	154	505
Denmark	33	65	261	308	801
Estonia	8	16	41	55	188
Finland	14	30	82	108	372
France	322	695	1727	2296	8278
Germany	367	783	2278	2884	9223
Greece	27	58	569	627	1179
Hungary	20	44	695	767	1352
Ireland	35	70	216	267	792
Italy	268	560	1761	2314	7676
Latvia	12	24	239	259	447
Lithuania	13	23	199	217	374
Luxembourg	3	7	44	49	108
Malta	2	4	12	15	52
Netherlands	113	234	622	797	2640
Poland	109	230	649	826	2738
Portugal	109	237	1168	1363	3390
Romania	46	93	590	731	1852
Slovakia	11	21	61	76	223
Slovenia	8	17	72	90	265
Spain	205	446	3112	3479	7348
Sweden	21	46	141	183	649
United Kingdom	758	1529	4575	5751	17467
Total EU-28	2659	5550	20420	25033	71652

6 Monetisation

6.1 Methodology

Valuation of human health co-benefits related to mortality and morbidity can be based on market values (e.g. average costs associated with treatment of an illness by the health care system, costs of medication, lost productivity in sick days) and/or non-market values (based on surveys estimating the value of a statistical life (VSL) or value of a life year (VOLY)).

The most suitable and practical approach for monetisation of human health depends on the health condition in consideration.

6.2 Excess cold weather deaths

Excess cold weather deaths are documented to occur predominantly to the population group aged 65 and above (Brophy, University College, Energy Research Group, University College, & Environmental Institute, 1999), but the exact age can not be known. Excesses in seasonal mortality occur due to two health conditions – cardiovascular diseases and respiratory diseases, but their share in each country is unknown. Also estimates of the cost burden of these diseases to the health care systems of the member states would require a substantial research inquiry into the specifics of the 28 EU member states. Therefore, it is advised to adopt non-market estimates of human life for the monetisation exercise of COMBI results.

Due to the predominant senior age of the population affected it is rather advised to adopt value of a life year (VOLY) estimates per (avoided) death assuming that the group affected would have lived at least one more year. This approach would represent a very conservative and cautious estimate – a piece of advice to be pursued in multiple benefit assessment studies in the context of greening or decarbonizing economies (Ürge-Vorsatz et al., 2016).

The latest estimate of the value of a statistical life in the EU is 3.37 million EUR (CI: 1.69 – 5.08 million EUR) in 2011 (see Table 17). Adjusting for GDP growth, purchasing power, inflation and elasticity, the value for 2015 is 3.60 million EUR (CI: 1.80 – 5.4 million EUR) in 2015.

Table 17: Value of a statistical life in the EU-28 in 2011, adjusted estimate to 2015 and value of a life year in 2015

	Lower bound	Average	Upper bound
VSL (2011), EUR	1,693,321	3,370,891	5,079,962
VSL (2015), EUR	1,798,566	3,597,132	5,395,698
VOLY (2015), EUR	57,645	115,290	172,935

Source: (Organisation for Economic Co-operation and Development (OECD), 2012)

VSL and VOLY values are believed to be related. VOLY is assumed to be constant throughout a person's life time and VSL is supposed to be a sum of VOLYs. Based on that

$$VSL = \sum_{0}^{t} \frac{VOLY}{(1+d)^t}$$

where t is life expectancy

and d – discount rate (Organisation for Economic Co-operation and Development (OECD), 2012).

As a result, VOLY of an average EU-28 citizen was worth around 115 000 EUR in 2015 (see Table 17).

As the levels of economic development vary greatly between different EU member states, there is rationale in customizing the VOLY value for every member state to monetise the co-impacts.

Customization of VSL can be performed according to the formula below (World Health Organization (WHO), 2017) :

$$VSL_{i,2015} = VSL_{EU28,2011} \times \left(\frac{GDP_{i,2011}}{GDP_{EU28,2011}}\right)^{0.8} \times PPP_{2011} \times (1 + \Delta P_{2015-2011}) \times (1 + \Delta GDP_{2015-2011})^{0.8}$$

where i – country in consideration,

GDP – gross domestic product,

PPP – purchasing power parity,

P – inflation ,

And 0.8 – income elasticity.

Customized VOLY estimates for each EU member state are obtained using the formula above (see Table 18). The highest value of VOLY among the EU-28 was for Luxembourg in 2015 – 344 291 EUR (CI: [172 146 – 516 437 EUR]). The lowest was for Bulgaria – 15 714 EUR (CI: [7 857 – 23 571]).

Table 18. Customized estimates of VSL and VOLY for 2015 for each EU-28 member state and average EU-28 estimates.

	Lower bound	VSL (2015), EUR	Upper bound	Lower bound	VOLY (2015), EUR	Upper bound
Austria	2,585,347	5,170,693	7,756,040	82,862	165,723	248,585
Belgium	2,445,500	4,890,998	7,336,497	78,379	156,759	235,138
Bulgaria	240,364	480,727	721,091	7,857	15,714	23,571
Croatia	580,996	1,161,992	1,742,988	18,796	37,592	56,389
Cyprus	1,339,762	2,679,523	4,019,285	42,815	85,630	128,444
Czech Rep.	879,801	1,759,602	2,639,403	28,372	56,743	85,115
Denmark	3,631,629	7,263,256	10,894,886	116,396	232,791	349,187
Estonia	727,978	1,455,956	2,183,935	23,551	47,103	70,654
Finland	2,658,672	5,317,342	7,976,014	84,963	169,927	254,890
France	2,285,513	4,571,025	6,856,538	73,038	146,076	219,115
Germany	2,312,294	4,624,587	6,936,882	74,110	148,220	222,331
Greece	1,117,521	2,235,042	3,352,564	35,817	71,634	107,451
Hungary	535,028	1,070,057	1,605,085	17,427	34,853	52,280
Ireland	3,308,770	6,617,538	9,926,308	105,739	211,477	317,215
Italy	1,766,620	3,533,239	5,299,859	56,297	112,593	168,890
Latvia	566,864	1,133,727	1,700,590	18,529	37,059	55,588
Lithuania	551,203	1,102,405	1,653,608	18,017	36,035	54,052
Luxembourg	5,386,784	10,773,565	16,160,349	172,146	344,291	516,437
Malta	1,078,163	2,156,325	3,234,488	34,455	68,910	103,365
Netherlands	2,737,383	5,474,764	8,212,147	87,479	174,957	262,436
Poland	510,969	1,021,938	1,532,906	16,531	33,061	49,592
Portugal	1,009,778	2,019,556	3,029,334	32,364	64,728	97,092
Romania	317,792	635,585	953,377	10,388	20,776	31,163
Slovakia	730,400	1,460,799	2,191,199	23,708	47,417	71,125
Slovenia	1,085,947	2,171,894	3,257,841	34,805	69,610	104,415
Spain	1,502,228	3,004,454	4,506,682	47,871	95,742	143,614
Sweden	3,287,660	6,575,318	9,862,978	105,064	210,128	315,192
United Kingdom	2,249,948	4,499,894	6,749,841	72,112	144,224	216,336
EU-28, average	**1,798,566**	**3,597,132**	**5,395,698**	**57,645**	**115,290**	**172,935**

Sources: (Organisation for Economic Co-operation and Development (OECD), 2012)

6.3 Asthma due to indoor dampness

Similarly as in the case of premature deaths due to indoor cold, market based estimates of economic damage caused by asthma morbidity would require a systematic inquiry into health care systems of EU member states. Whereas non-market valuation methods propose a rather simple solution that is in line with damage estimates of premature mortality due to indoor cold. Each disease or health impairment gets a disability weight in the burden of disease methodology and they range from 0 to 1, where 1 equals death (Global Health Data Exchange (GHDx), 2017). Therefore, 1 DALY equals to one life year lost (Cropper & Khanna, 2014) or for instance in case of partially controlled asthma – 25 people ill with this type of asthma. One life year lost can be easily monetised using the same VOLY values. Thus the values elaborated in Table 18 can be used for straightforward monetisation of burden of disease expressed in DALYs.

6.4 Monetisation of co-benefits: avoided premature mortality due to indoor cold

Monetisation of excess cold weather mortality results is provided in two tables – see Table 19 and Table 20. Table 19 presents quantification results using customized monetary values for each member state of the EU – a more realistic approach chosen for communication of the main outcomes of COMBI research. While the Table 20 proposes to give a second glance at the results in case the human life would be valued equally across the EU – a more ethical approach.

To sum up, the economic value of premature mortality due to indoor cold in 2015 amounted to 6.7 billion EUR using customized VOLY values and 8 billion EUR using the universal average VOLY values for the whole of the EU. Almost all of these could be avoided by 2030 if the society diverted the financial resources previewed in COMBI towards the socially vulnerable first.

Under the "no emphasis on social policy" scenario the avoided economic damage as a result of premature mortality would amount to 323.1 million EUR under reference scenario and 676.3 million EUR under efficiency scenario. In the case of "prioritizing the socially vulnerable" scenario 1.9 billion EUR of economic damage could be avoided under reference scenario and 2.5 billion EUR under efficiency scenario. To sum up, depending on social policy the avoided economic damage due to premature mortality due to indoor cold in 2030 in the EU-28 would range from 323.1 million EUR under the "no emphasis on social policy" reference scenario to 2.5 billion EUR under the "prioritizing socially vulnerable" efficiency scenario (see Table 19; highlighted in light green).

Table 19: Monetisation of avoided premature mortality due to reduced exposure to indoor cold using customized VOLY (2015) values for each member state of the EU

	Scenario "No emphasis on social policy"				Scenario "Prioritizing the socially vulnerable"				2015	
	Reference		Efficiency		Reference		Efficiency			
	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Average annual ECWDs, number of deaths	Economic value of premature mortality, million EUR
Austria	17	2.9	37	6.1	124	20.5	168	27.9	473	78.4
Belgium	72	11.2	143	22.4	456	71.6	563	88.3	1365	214.0
Bulgaria	102	1.6	233	3.7	891	14.0	1053	16.6	2598	40.8
Croatia	28	1.1	52	1.9	271	10.2	315	11.8	624	23.5
Cyprus	4	0.4	8	0.7	40	3.4	46	4.0	95	8.1
Czech Rep.	60	3.4	127	7.2	260	14.8	352	20.0	1025	58.2
Denmark	16	3.7	32	7.5	104	24.2	127	29.6	305	70.9
Estonia	5	0.2	11	0.5	23	1.1	32	1.5	98	4.6
Finland	11	1.9	23	4.0	52	8.9	72	12.3	220	37.3
France	345	50.3	743	108.5	1535	224.2	2133	311.6	6782	990.7
Germany	231	34.3	493	73.1	1178	174.6	1555	230.5	4464	661.7
Greece	41	2.9	87	6.2	677	48.5	764	54.7	1370	98.1
Hungary	46	1.6	99	3.5	1218	42.5	1375	47.9	2316	80.7

Ireland	30	6.3	60	12.6	151	31.9	194	41.0	519	109.9
Italy	513	57.8	1077	121.2	2816	317.1	3864	435.1	11379	1,281.2
Latvia	27	1.0	55	2.0	433	16.0	479	17.8	793	29.4
Lithuania	34	1.2	64	2.3	436	15.7	484	17.4	800	28.8
Luxembourg	1	0.3	2	0.6	8	2.8	9	3.2	20	6.8
Malta	4	0.3	9	0.6	22	1.5	28	2.0	86	5.9
Netherlands	38	6.7	79	13.8	174	30.4	232	40.7	686	120.0
Poland	323	10.7	682	22.6	1584	52.4	2100	69.4	6238	206.2
Portugal	136	8.8	294	19.1	1169	75.7	1408	91.1	3257	210.8
Romania	236	4.9	478	9.9	2449	50.9	3157	65.6	7276	151.2
Slovakia	24	1.1	49	2.3	113	5.4	148	7.0	389	18.4
Slovenia	8	0.6	18	1.2	61	4.3	79	5.5	212	14.8
Spain	200	19.1	435	41.6	2415	231.2	2768	265.1	5541	530.5
Sweden	26	5.4	56	11.8	141	29.5	190	39.9	600	126.0
United Kingdom	579	83.4	1174	169.3	2901	418.4	3797	547.6	10367	1,495.2
Total EU-28	3156	323.1	6620	676.3	21702	1,941.5	27496	2,505.1	69899	6,702.4

Table 20: Monetisation of avoided premature mortality due to reduced exposure to indoor cold using average VOLY (2015) for EU-28 values

	Scenario "No emphasis on social policy"				Scenario "Prioritizing the socially vulnerable"				2015	
	Reference		Efficiency		Reference		Efficiency			
	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Avoided ECWDs, number of deaths	Economic value of avoided premature mortality, million EUR (at constant 2015 VOLY values)	Average annual ECWDs, number of deaths	Economic value of premature mortality, million EUR
Austria	17	2.0	37	4.3	124	14.3	168	19.4	473	54.6
Belgium	72	8.3	143	16.5	456	52.6	563	65.0	1365	157.4
Bulgaria	102	11.7	233	26.9	891	102.7	1053	121.4	2598	299.6
Croatia	28	3.3	52	6.0	271	31.2	315	36.3	624	71.9
Cyprus	4	0.5	8	0.9	40	4.6	46	5.4	95	10.9
Czech Rep.	60	7.0	127	14.7	260	30.0	352	40.6	1025	118.2
Denmark	16	1.9	32	3.7	104	12.0	127	14.6	305	35.1
Estonia	5	0.6	11	1.3	23	2.7	32	3.7	98	11.3
Finland	11	1.3	23	2.7	52	6.0	72	8.3	220	25.3
France	345	39.7	743	85.6	1535	176.9	2133	246.0	6782	781.9
Germany	231	26.7	493	56.9	1178	135.8	1555	179.3	4464	514.7
Greece	41	4.7	87	10.0	677	78.1	764	88.0	1370	157.9
Hungary	46	5.3	99	11.5	1218	140.4	1375	158.5	2316	267.0

Ireland	30	3.4	60	6.9	151	17.4	194	22.4	519	59.9
Italy	513	59.1	1077	124.1	2816	324.7	3864	445.5	11379	1,311.9
Latvia	27	3.1	55	6.4	433	49.9	479	55.3	793	91.5
Lithuania	34	3.9	64	7.3	436	50.2	484	55.8	800	92.2
Luxembourg	1	0.1	2	0.2	8	0.9	9	1.1	20	2.3
Malta	4	0.5	9	1.0	22	2.5	28	3.3	86	9.9
Netherlands	38	4.4	79	9.1	174	20.0	232	26.8	686	79.1
Poland	323	37.2	682	78.7	1584	182.6	2100	242.2	6238	719.1
Portugal	136	15.7	294	33.9	1169	134.8	1408	162.3	3257	375.4
Romania	236	27.2	478	55.1	2449	282.3	3157	364.0	7276	838.9
Slovakia	24	2.8	49	5.6	113	13.1	148	17.0	389	44.8
Slovenia	8	0.9	18	2.0	61	7.1	79	9.1	212	24.4
Spain	200	23.0	435	50.1	2415	278.4	2768	319.2	5541	638.8
Sweden	26	3.0	56	6.5	141	16.2	190	21.9	600	69.2
United Kingdom	579	66.7	1174	135.4	2901	334.5	3797	437.8	10367	1,195.2
Total EU-28	**3156**	**363.8**	**6620**	**763.2**	**21702**	**2,502.0**	**27496**	**3,170.0**	**69899**	**8,058.6**

6.5 Monetisation of co-benefits: avoided asthma morbidity due to indoor dampness

Monetisation of asthma co-benefits projected for 2030 under different scenarios can be found in Table 21 and Table 22. Table 21 presents quantification results using customized monetary values for each member state of the EU – a more realistic approach chosen for communication of the main outcomes of COMBI research. While the Table 22 proposes to give a second glance at the results in case the human life would be valued equally across the EU – a more ethical approach.

Overall the total economic damage estimates on the EU-28 level of the total burden of disease of asthma and excess cold weather mortality are very similar. The economic cost of asthma due to indoor dampness in 2015 was 8.75 billion EUR using customized VOLY estimates and 8.26 billion EUR using average VOLY estimates for all EU-28.

The total cost of avoided asthma morbidity would amount to 2.36 billion EUR under the "prioritizing the socially vulnerable" reference scenario and it would stand at 2.94 billion EUR under the "prioritizing the socially vulnerable" efficiency scenario. Under "no emphasis on social policy" scenario the avoided cost stands at 338 million EUR under COMBI reference scenario and 703 million EUR under COMBI efficiency scenario (see Table 21). To re-iterate again – if all financial resources projected in COMBI could be diverted to socially vulnerable first in most of the EU-28 countries under both scenarios asthma due to dampness could be eliminated. To sum up, depending on social policy the avoided economic damage due to asthma morbidity due to indoor dampness in 2030 in the EU-28 would range from 338 million EUR under the "no emphasis on social policy" reference scenario to 2.94 billion EUR under the "prioritizing socially vulnerable" efficiency scenario (see Table 21; highlighted in light green).

Table 21: Monetisation of avoided asthma morbidity due to reduced exposure to indoor dampness using customized VOLY (2015) values for each member state of the EU

	Scenario "No emphasis on social policy"				Scenario "Prioritizing socially vulnerable"				2015	
	Reference		Efficiency		Reference		Efficiency			
	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Asthma burden of disease due to indoor dampness, DALYs	Economic value of burden of disease, million EUR
Austria	26	4.3	55	9.2	224	37.0	292	48.4	919	152.2
Belgium	67	10.5	133	20.8	520	81.5	619	97.1	1634	256.1
Bulgaria	16	0.3	38	0.6	181	2.8	207	3.3	546	8.6
Croatia	12	0.5	22	0.8	141	5.3	160	6.0	337	12.7
Cyprus	11	0.9	19	1.7	121	10.3	137	11.7	298	25.6
Czech Rep.	23	1.3	48	2.7	119	6.7	154	8.7	505	28.7
Denmark	33	7.7	65	15.2	261	60.7	308	71.7	801	186.4
Estonia	8	0.4	16	0.8	41	1.9	55	2.6	188	8.9
Finland	14	2.5	30	5.2	82	13.9	108	18.4	372	63.2
France	322	47.0	695	101.5	1727	252.3	2296	335.4	8278	1209.2
Germany	367	54.3	783	116.1	2278	337.7	2884	427.5	9223	1367.0
Greece	27	1.9	58	4.1	569	40.8	627	44.9	1179	84.5
Hungary	20	0.7	44	1.5	695	24.2	767	26.7	1352	47.1
Ireland	35	7.4	70	14.9	216	45.7	267	56.6	792	167.6
Italy	268	30.1	560	63.1	1761	198.2	2314	260.6	7676	864.3
Latvia	12	0.4	24	0.9	239	8.9	259	9.6	447	16.6
Lithuania	13	0.5	23	0.8	199	7.2	217	7.8	374	13.5

Luxembourg	3	1.2	7	2.4	44	15.1	49	16.9	108	37.2
Malta	2	0.1	4	0.3	12	0.8	15	1.1	52	3.6
Netherlands	113	19.9	234	41.0	622	108.8	797	139.5	2640	461.9
Poland	109	3.6	230	7.6	649	21.5	826	27.3	2738	90.5
Portugal	109	7.1	237	15.3	1168	75.6	1363	88.2	3390	219.4
Romania	46	1.0	93	1.9	590	12.3	731	15.2	1852	38.5
Slovakia	11	0.5	21	1.0	61	2.9	76	3.6	223	10.6
Slovenia	8	0.5	17	1.2	72	5.0	90	6.2	265	18.4
Spain	205	19.6	446	42.7	3112	297.9	3479	333.1	7348	703.5
Sweden	21	4.4	46	9.7	141	29.7	183	38.5	649	136.3
United Kingdom	758	109.4	1529	220.5	4575	659.9	5751	829.4	17467	2519.1
Total EU-28	**2659**	**338.0**	**5550**	**703.5**	**20420**	**2364.7**	**25033**	**2935.9**	**71652**	**8751.0**

Table 22: Monetisation of avoided asthma morbidity due to reduced exposure to indoor dampness using average VOLY (2015) for EU-28 values

	Scenario "No emphasis on social policy"				Scenario "Prioritizing socially vulnerable"				2015	
	Reference		Efficiency		Reference		Efficiency			
	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Avoided asthma burden of disease due to dampness in 2030, DALYs	Economic value of avoided burden of disease, million EUR (at constant 2015 VOLY values)	Asthma burden of disease due to indoor dampness, DALYs	Economic value of burden of disease, million EUR
Austria	26	3.0	55	6.4	224	25.8	292	33.6	919	105.9
Belgium	67	7.7	133	15.3	520	59.9	619	71.4	1634	188.4
Bulgaria	16	1.9	38	4.4	181	20.8	207	23.9	546	62.9
Croatia	12	1.4	22	2.5	141	16.3	160	18.4	337	38.9
Cyprus	11	1.2	19	2.2	121	13.9	137	15.8	298	34.4
Czech Rep.	23	2.6	48	5.5	119	13.7	154	17.7	505	58.2
Denmark	33	3.8	65	7.5	261	30.1	308	35.5	801	92.3
Estonia	8	0.9	16	1.9	41	4.7	55	6.3	188	21.7
Finland	14	1.7	30	3.5	82	9.4	108	12.5	372	42.9
France	322	37.1	695	80.1	1727	199.1	2296	264.7	8278	954.4
Germany	367	42.3	783	90.3	2278	262.7	2884	332.5	9223	1063.3
Greece	27	3.1	58	6.7	569	65.6	627	72.3	1179	136.0
Hungary	20	2.4	44	5.1	695	80.1	767	88.4	1352	155.8

Ireland	35	4.1	70	8.1	216	24.9	267	30.8	792	91.3
Italy	268	30.9	560	64.6	1761	203.0	2314	266.8	7676	885.0
Latvia	12	1.4	24	2.8	239	27.6	259	29.9	447	51.6
Lithuania	13	1.5	23	2.7	199	22.9	217	25.0	374	43.1
Luxembourg	3	0.4	7	0.8	44	5.0	49	5.6	108	12.5
Malta	2	0.2	4	0.5	12	1.4	15	1.8	52	6.0
Netherlands	113	13.1	234	27.0	622	71.7	797	91.9	2640	304.4
Poland	109	12.6	230	26.6	649	74.9	826	95.2	2738	315.6
Portugal	109	12.6	237	27.3	1168	134.7	1363	157.1	3390	390.8
Romania	46	5.3	93	10.7	590	68.0	731	84.3	1852	213.6
Slovakia	11	1.2	21	2.5	61	7.0	76	8.8	223	25.7
Slovenia	8	0.9	17	2.0	72	8.3	90	10.3	265	30.5
Spain	205	23.6	446	51.4	3112	358.8	3479	401.1	7348	847.1
Sweden	21	2.4	46	5.3	141	16.3	183	21.1	649	74.8
United Kingdom	758	87.4	1529	176.3	4575	527.5	5751	663.0	17467	2013.7
Total EU-28	**2659**	**306.6**	**5550**	**639.9**	**20420**	**2354.2**	**25033**	**2886.1**	**71652**	**8260.8**

7 Conclusions and outlook

The main objective of the COMBI project (Calculating and Operationalizing the Multiple Benefits of Energy Efficiency in Europe) was to capture the multiple impacts of energy efficiency while using the same energy activity data in various fields of research and policy: air pollution, resource efficiency, social welfare, economy and energy security. This report has been renamed to reflect a narrower scope adopted for the social welfare work package – public health co-benefits in relation to energy poverty. Air pollution-related public health aspects have been explored in COMBI report 3.4.

Background. Households that are considered to be energy poor often are characterized by inadequate conditions for well-being indoors – indoor cold during the cold season and/or indoor dampness. According to the European Union's Survey on Income and Living Conditions (EU SILC) 9.4% of European Union's population were unable to keep their homes adequately warm and 15.2% lived in residential housing characterized by leaking roof, damp walls, floors or foundation, and rot in window frames or floors in 2015 – base year for COMBI assessment. Indoor cold is related to excess morbidity and mortality due to respiratory and cardiovascular diseases during the cold season. Indoor dampness is related to mould growth, which in turn may give rise to asthma. These health implications in turn are related to diminished well-being, public and private costs in relation to health care and reduced productivity. Energy efficiency measures applied in the existing residential housing, such as building envelope insulation, replacement or installation of heating, ventilation and air conditioning systems are believed to mitigate the extent of these health conditions. As well as improved energy efficiency standards of new buildings are believed to prevent from energy poverty related health implications.

Methods. This report quantifies the impact of energy efficiency interventions on energy poverty-related public health conditions – excess cold weather deaths due to indoor cold exposure and asthma due to indoor dampness exposure. The starting point of this research was to evaluate the current extent of burden of disease in relation to these residential housing-related conditions. Due to recent methodological critiques the formula of excess winter deaths has been updated and in relation to that the terminology has been changed – instead excess cold weather deaths have been calculated and used for modelling the impacts in 2030. Burden of disease approach has been used to evaluate the extent of asthma morbidity due to indoor dampness across the 28 member states of the European Union. The current burden of disease in 2015 has been used as a baseline for comparisons and in modelling for 2030 – it has been assumed that the annual burden of disease remained the same in relation to all other factors with the exception of changes in the two factors at the focus of COMBI – indoor cold and indoor dampness (ceteris paribus). The prevalence of indoor cold and indoor dampness is modelled in relation to the extent and type of changes in the residential housing stock and the extent of social welfare policies.

Baseline. The analysis of the monthly mortality data across the populations of the EU-28 in 1996-2014 has revealed different patterns in relation to seasonal mortality. The largest values of excess cold weather mortality index were found for Malta (30.6%), Portugal (23.1%), Cyprus (19.2%), and the smallest for Finland (6.2%), Slovakia (6.6%), Czech Republic (8.6%). In absolute terms, excess cold weather deaths accounted for around 323 000 cases annually in 1996-2014. Out of those, around 70 000 on average annually could be attributed to indoor cold exposure. Assuming that these are premature deaths and the affected population would have lived at least for another year, the economic value of a societal loss would be 6.7 billion EUR at 2015 prices applying Value Of a Life Year (VOLY) estimates.

Asthma onset can be initiated due to many trigger factors and indoor dampness is one of them. Attribution of the total asthma burden to indoor dampness alone depends on relative risk estimates and prevalence of indoor dampness conditions in the population. Indoor dampness is responsible for 1.75% of the total burden of disease of asthma in Finland (lowest value), and 8.86% in Slovenia (highest value). The burden of disease of asthma attributable to indoor dampness amounted to over 71 000 Disability Adjusted Life-Years (DALYs) in 2015. Applying Value Of a Life Year (VOLY) estimates this constituted a societal loss of 8.7 billion EUR in 2015.

Projections for 2030. The public health implications of the two energy activity scenarios have been explored along with a few cases of social policy sensitivities.

Socially vulnerable first

Energy efficiency may be unaffordable to the socially vulnerable groups and in the absence of a social policy, in this regard, no public health co-benefits would be achieved. There is a mismatch between those who can afford energy efficiency retrofits and those who need them the most and would benefit from them the most (not only energy savings, but also improved health). Comparing the extent of the energy efficiency interventions in the residential sector under both scenarios in 2030 and the current prevalence of indoor cold and indoor dampness, in theory diverting all of the projected resources to the socially vulnerable should eradicate nearly all premature excess cold weather deaths and indoor dampness-related asthma ("*socially vulnerable first*" social policy scenario). The societal value of public health co-benefits would be maximized.

No emphasis on social policy

The second combination of scenarios explored is of minimal social welfare policy in dealing with energy poverty via improving the energy efficiency of the residential housing ("*no emphasis on social policy*" scenario). In this case, under the COMBI reference scenario just over 3 000 premature deaths due to exposure to indoor cold would be avoided in the year 2030 in the EU-28. Under the COMBI efficiency scenario around 6 600 premature excess cold weather deaths would be avoided in the year 2030 in the EU-28. These two figures constitute an avoided societal loss of 323 million EUR and 676 million EUR respectively applying VOLY estimates at 2015 prices. The co-benefits of additional energy efficiency improvement actions in 2030 amount to around 3 600 avoided premature deaths due to indoor cold – an avoided economic loss to the society of 353 million EUR.

The avoided asthma morbidity under the COMBI reference scenario would stand at around 2 700 DALYs and under the COMBI Efficiency scenario – at around 5 500 DALYs in the EU-28. The avoided economic loss would stand at 338 million EUR and 703 million EUR respectively in 2030 applying VOLY estimates at 2015 prices.. The difference between COMBI reference and efficiency scenarios stands at 2 800 DALYs and associated avoided economic damage of 365 million EUR.

Prioritizing socially vulnerable

The last combination of energy activity pathway and social policy scenarios assumes that the European Union member states accelerate their social welfare policies in curing the energy poverty problem by subsidizing the energy efficiency interventions for the socially vulnerable – "*prioritizing socially vulnerable*" scenario. Under the COMBI reference scenario around 22 000 premature deaths due to energy poverty could be avoided in the year 2030. Under the COMBI efficiency scenario the figure could be increased up to 27 500 of avoided annual deaths in 2030. The economic value of avoided societal loss would be 1.9 billion EUR and 2.5 billion EUR respectively. The difference between the reference and efficiency scenarios points to the co-benefits of the additional energy efficiency improvement actions – around 5 500 avoided premature deaths due to indoor cold – an avoided economic loss to the society of 563 million EUR in 2030.

The avoided asthma morbidity under the COMBI reference scenario would amount to around 20 000 DALYs and under the COMBI efficiency scenario – at around 25 000 DALYs. The avoided economic loss would stand at 2.4 billion EUR and 2.9 billion EUR respectively in 2030 applying VOLY estimates at 2015 prices. The difference between COMBI reference and efficiency scenarios stands at 5 000 DALYs and associated avoided economic damage of 571 million EUR.

Conclusion

To sum up, the public health impact and value of energy efficiency improvement actions ranges depending on the extent of residential housing retrofits (aspect of quantity), the depth of residential housing retrofits (aspect of quality) –both covered by COMBI scenarios - and social policy extent as modeled in this research report. Therefore, the public health impact of energy efficiency improvement actions in 2030 in the EU-28 ranges from

- a minimum of just over 3 000 of premature deaths avoided due to indoor cold to around 27 500 of avoided premature deaths;
- a minimum of 2 700 DALYs of asthma morbidity avoided due to indoor dampness to around 25 000 DALYs.

The economic value of avoided public health damage in 2030 ranges

- from a minimum of 323 million EUR to a maximum of 2.5 billion EUR due to premature mortality due to indoor cold;
- from a minimum of 338 million EUR to a maximum of 2.9 billion EUR due to asthma morbidity due to indoor dampness.

The co-benefits of additional energy efficiency improvement actions coupled with strong social policies in 2030 could deliver these additional gains in public health:

- around 24 500 avoided premature deaths due to indoor cold and the avoided economic damage of 2.2 billion EUR

- around 22 300 DALYs of avoided asthma due to indoor dampness. and the avoided economic damage of 2.6 billion EUR

Discussion and outlook

- Only sufficiently well operationalized health impacts have been quantified in this report, meaning that the value of co-impacts is likely underestimated. More research is needed both at a micro level via randomized control trials and at a macro level to decrease uncertainties around burden of disease attribution. A more holistic picture of public health impacts of energy efficiency improvement actions in buildings is needed to enable such extended macro scale assessments.
- A pan-European study would be appropriate to assess the extent of public health improvements accounting for climatic differences and differences in building standards. As this research has shown, there are still significant uncertainties in the attribution of burden of disease due to indoor dampness and indoor cold, as well as uncertainties with regard to sufficiency of technological fixes (in this case energy efficiency) to the human health problems in question.
- Due to a rather large disability weight attributed to mental health illnesses, one of the potentially most significant impacts of energy poverty on health is mental health impairment. This area is still under researched and overlooked; quantification of this human health impact is missing due to insufficient operationalization and lack of attribution methods of mental health impairments to energy poverty.
- Monetisation in this study was carried out only using estimates of the value of a human life, not the actual market values of productivity loss, costs of hospitalization, medication and medical care. Full damage accounting should include all these categories. In the current form, COMBI results present a conservative estimate of economic loss to the society due to inadequate housing conditions.
- Other public health impacts in relation to air pollution have been explored in COMBI report D3.4

8 Annexes

Table 23. Share of population unable to keep their home adequately warm- EU-SILC survey and selected attribution rate of excess cold weather deaths to indoor cold.

	Inability to keep home adequately warm - EU-SILC survey, %							
	2010	2011	2012	2013	2014	2015	Average, 2010-2015	Attribution rate of ECWDs to indoor cold, %
Austria	3.8	2.7	3.2	2.7	3.2	2.6	3.0	10
Belgium	5.6	7.1	6.6	5.8	5.4	5.2	6.0	20
Bulgaria	66.5	46.3	46.5	44.9	40.5	39.2	47.3	30
Croatia	8.3	9.8	10.2	9.9	9.7	9.9	9.6	20
Cyprus	27.3	26.6	30.7	30.5	27.5	28.3	28.5	30
Czech Rep.	5.2	6.4	6.7	6.2	6.1	5.0	5.9	20
Denmark	1.9	2.3	2.5	3.8	2.9	3.6	2.8	10
Estonia	3.1	3.0	4.2	2.9	1.7	2.0	2.8	10
Finland	1.4	1.8	1.5	1.2	1.5	1.7	1.5	10
France	5.7	6.0	6.0	6.6	5.9	5.5	6.0	20
Germany	5.0	5.2	4.7	5.3	4.9	4.1	4.9	10
Greece	15.4	18.6	26.1	29.5	32.9	29.2	25.3	30
Hungary	10.7	12.2	15.0	14.6	11.6	9.6	12.3	30
Ireland	6.8	6.8	8.4	10.0	8.9	9.0	8.3	20
Italy	11.6	17.8	21.3	18.8	18.0	17.0	17.4	30
Latvia	19.1	22.5	19.9	21.1	16.8	14.5	19.0	30
Lithuania	25.2	36.2	34.1	29.2	26.5	31.1	30.4	30
Luxembourg	0.5	0.9	0.6	1.6	0.6	0.9	0.9	10
Malta	14.3	17.6	22.1	23.4	22.1	13.9	18.9	30
Netherlands	2.3	1.6	2.2	2.9	2.6	2.9	2.4	30
Poland	14.8	13.6	13.2	11.4	9.0	7.5	11.6	30
Portugal	30.1	26.8	27.0	27.9	28.3	23.8	27.3	30
Romania	20.1	15.6	15.0	14.7	12.9	13.1	15.2	30
Slovakia	4.4	4.3	5.5	5.4	6.1	5.8	5.3	20
Slovenia	4.7	5.4	6.1	4.9	5.6	5.6	5.4	20
Spain	7.5	6.5	9.1	8.0	11.1	10.6	8.8	20
Sweden	1.7	1.6	1.4	0.8	0.8	1.2	1.3	10
United Kingdom	6.1	6.5	8.1	10.6	9.4	7.8	8.1	20

Sources: (Eurostat, 2016b).

Table 24. Residential building stock profile in the EU-28 in 2015.

		No change	Building retrofits			New buildings		
	Total stock of residential dwellings, thousands	Stock of surviving, non-retrofitted dwellings, % of total	LIGHT RETROFIT, % of total	MEDIUM RETROFIT, % of total	DEEP RETROFIT, % of total	New dwellings: BASE CASE 2020), % of total	nZEBs % of total	PASSIVE HOUSES % of total
Austria	3,827.128	94.56	0.43	0.41	0.60	1.91	2.00	0.10
Belgium	4,713.295	96.64	0.58	0.55	0.34	1.25	0.60	0.05
Bulgaria	2,944.085	93.27	1.03	0.25	0.13	3.54	1.64	0.13
Croatia	1,523.615	96.29	0.54	0.45	0.49	1.35	0.81	0.07
Cyprus	296.125	96.22	0.54	0.45	0.49	1.39	0.84	0.07
Czech Rep.	4,657.833	94.15	0.58	0.63	0.22	2.93	1.37	0.11
Denmark	2,380.147	96.13	0.63	0.55	0.29	1.59	0.76	0.06
Estonia	573.292	95.55	0.55	0.51	0.39	1.98	0.94	0.08
Finland	2,630.248	95.24	0.55	0.50	0.39	2.19	1.03	0.09
France	29,005.005	93.57	0.56	0.53	0.33	0.00	4.88	0.13
Germany	40,376.744	95.26	0.62	0.54	0.29	2.08	1.13	0.09
Greece	4,389.159	96.98	0.54	0.45	0.49	1.01	0.49	0.04
Hungary	4,157.772	96.65	0.10	0.52	0.84	1.25	0.59	0.05
Ireland	1,717.121	97.41	0.63	0.55	0.29	0.72	0.36	0.03
Italy	25,864.973	95.66	0.53	0.44	0.48	1.88	0.93	0.07
Latvia	833.949	98.18	0.57	0.52	0.40	0.21	0.11	0.01
Lithuania	1,333.493	97.86	0.57	0.52	0.40	0.43	0.21	0.02
Luxem-bourg	229.766	92.57	0.60	0.53	0.28	4.00	1.87	0.15
Malta	151.477	93.66	0.72	0.40	0.30	3.28	1.52	0.12
Nether-lands	7,644.283	95.75	0.62	0.54	0.29	1.85	0.88	0.07
Poland	14,154.614	93.27	0.61	0.53	0.28	3.60	1.58	0.14
Portugal	4,089.978	96.46	0.74	0.42	0.31	1.37	0.65	0.05
Romania	7,492.031	97.30	0.10	0.53	0.85	0.89	0.30	0.03
Slovakia	1,852.381	96.03	0.59	0.64	0.22	1.66	0.79	0.07
Slovenia	885.280	93.43	0.52	0.43	0.47	3.42	1.60	0.13
Spain	18,408.791	96.63	0.74	0.42	0.31	1.40	0.46	0.05
Sweden	5,114.240	88.21	0.51	0.47	0.36	6.94	3.24	0.27
United Kingdom	28,303.042	97.68	0.59	0.55	0.35	0.54	0.28	0.02

Source: COMBI input data.

Table 25.Residential building stock profile in the EU-28 in 2030 under the COMBI reference scenario.

		No change	Building retrofits			New buildings		
	Total stock of residential dwellings, thousands	Stock of surviving, non-retrofitted dwellings, % of total	LIGHT RETROFIT, % of total	MEDIUM RETROFIT, % of total	DEEP RETROFIT, % of total	New dwellings: BASE CASE 2020), % of total	nZEBs % of total	PASSIVE HOUSES % of total
Austria	4,630.626	66.75	2.43	3.53	5.37	2.16	11.98	7.80
Belgium	6,375.220	60.95	3.08	4.46	2.80	2.34	15.52	10.85
Bulgaria	3,956.961	56.49	5.10	3.05	1.58	3.09	16.39	14.30
Croatia	2,361.086	51.02	2.45	3.05	3.38	3.23	22.31	14.57
Cyprus	465.055	52.46	2.44	3.06	3.39	3.23	21.59	13.81
Czech Rep.	5,617.302	66.66	2.35	6.59	2.36	3.22	11.09	7.72
Denmark	3,269.122	59.66	3.27	4.44	2.42	2.65	16.27	11.29
Estonia	624.300	69.49	3.57	4.92	3.84	2.35	9.06	6.76
Finland	3,018.794	69.11	3.38	4.72	3.68	2.53	9.59	6.99
France	32,657.044	68.57	3.50	5.04	3.17	0.00	13.00	6.71
Germany	48,824.320	66.43	3.67	4.97	2.72	2.21	11.13	8.87
Greece	7,136.614	46.16	2.23	2.76	3.06	1.34	23.17	21.29
Hungary	7,110.551	43.35	0.64	2.55	4.36	1.37	24.67	23.07
Ireland	2,159.106	65.84	3.62	4.91	2.68	1.63	12.36	8.95
Italy	30,735.618	68.79	3.20	4.02	4.45	2.27	10.02	7.26
Latvia	1,441.607	42.15	2.21	3.02	2.36	0.88	27.16	22.22
Lithuania	1,956.894	41.63	2.36	3.16	2.47	1.97	36.35	12.06
Luxem-bourg	368.581	49.08	2.69	3.65	2.00	4.60	22.67	15.31
Malta	185.231	66.07	4.23	3.92	3.00	3.78	11.76	7.24
Nether-lands	9,004.671	67.88	3.74	5.06	2.77	2.34	10.57	7.64
Poland	17,028.503	65.46	3.60	4.88	2.67	3.84	11.59	7.96
Portugal	5,535.689	58.35	3.86	3.55	2.71	1.50	15.77	14.26
Romania	9,540.648	62.53	0.91	3.62	6.20	1.34	13.48	11.91
Slovakia	2,287.113	64.66	2.33	6.50	2.33	2.40	12.75	9.03
Slovenia	1,061.175	62.68	2.97	3.70	4.10	3.40	12.90	10.25
Spain	27,719.413	51.15	3.39	3.11	2.38	1.56	19.91	18.51
Sweden	5,784.442	62.75	3.10	4.31	3.37	6.82	12.12	7.53
United Kingdom	35,121.137	67.24	3.40	4.91	3.09	1.39	11.50	8.45

Source: COMBI input data.

Table 26. Residential building stock profile in the EU-28 in 2030 under the COMBI efficiency scenario.

		No change	Building retrofits			New buildings		
	Total stock of residential dwellings, thousands	Stock of surviving, non-retrofitted dwellings, % of total	LIGHT RETROFIT, % of total	MEDIUM RETROFIT, % of total	DEEP RETROFIT, % of total	New dwellings: BASE CASE 2020), % of total	nZEBs % of total	PASSIVE HOUSES % of total
Austria	4,630.626	55.21	5.22	6.94	10.69	2.16	8.26	11.51
Belgium	6,375.220	50.40	6.83	8.63	5.43	2.34	10.30	16.07
Bulgaria	3,956.961	46.57	11.47	5.38	2.79	3.09	10.33	20.36
Croatia	2,361.086	41.97	5.39	5.93	6.62	3.23	15.01	21.86
Cyprus	465.055	43.40	5.37	5.95	6.64	3.23	14.59	20.82
Czech Rep.	5,617.302	55.13	4.80	13.23	4.80	3.22	7.41	11.41
Denmark	3,269.122	49.33	7.27	8.48	4.71	2.65	10.83	16.73
Estonia	624.300	56.85	7.89	9.58	7.51	2.35	5.95	9.87
Finland	3,018.794	57.15	7.45	9.14	7.16	2.53	6.34	10.24
France	32,657.044	56.69	7.72	9.74	6.13	0.00	9.84	9.87
Germany	48,824.320	54.83	8.16	9.51	5.28	2.21	7.21	12.79
Greece	7,136.614	38.04	4.86	5.34	5.96	1.34	14.31	30.15
Hungary	7,110.551	35.77	1.27	5.04	8.81	1.37	15.16	32.58
Ireland	2,159.106	54.41	8.04	9.38	5.21	1.63	8.14	13.18
Italy	30,735.618	56.89	7.05	7.80	8.70	2.27	6.63	10.65
Latvia	1,441.607	34.42	4.86	5.87	4.60	0.88	17.30	32.08
Lithuania	1,956.894	33.65	5.10	6.09	4.77	1.97	26.72	21.70
Luxem-bourg	368.581	40.57	5.99	6.98	3.88	4.60	15.18	22.79
Malta	185.231	54.70	9.48	7.33	5.71	3.78	8.05	10.94
Nether-lands	9,004.671	56.13	8.29	9.66	5.37	2.34	6.98	11.23
Poland	17,028.503	54.09	8.01	9.33	5.19	3.84	7.75	11.79
Portugal	5,535.689	48.01	8.65	6.64	5.17	1.50	9.80	20.23
Romania	9,540.648	51.63	1.82	7.21	12.61	1.34	8.40	16.99
Slovakia	2,287.113	53.26	4.76	13.06	4.74	2.40	8.46	13.33
Slovenia	1,061.175	51.81	6.49	7.16	7.99	3.40	8.35	14.80
Spain	27,719.413	42.15	7.56	5.80	4.51	1.56	12.23	26.19
Sweden	5,784.442	51.86	6.81	8.33	6.53	6.82	8.36	11.29
United Kingdom	35,121.137	55.62	7.53	9.51	5.99	1.39	7.55	12.41

Source: COMBI input data.

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