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Study on cost and benefits of working towards environmental macro objectives in the building sector

Final Report and Annex for the European Commission, DG Environment

Rotterdam, 24 October 2017

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Abstract

The European Commission's 2014 Communication on Resource Efficiency Opportunities in the Building Sector identifies the need for a common EU approach to assess the environmental performance of buildings. This is structured in six environmental macro objectives: 1) reducing greenhouse gas emissions from building life cycle energy use, 2) resource efficient and circular material life cycles, 3) efficient use of water resources, 4) healthy and comfortable spaces, 5) adaptation and resilience to climate change, and 6) optimised life cycle cost and value.

This study explores the possibility to implement mature and easy-to-implement actions for each of these macro objectives formulating a concise action package for each one of the six macro objectives. The actions put forward are relevant for buildings across Europe and can be applied to a significant portion of the European building stock addressing the needs of both new and existing, residential and office buildings. The potential costs and benefits of implementing these actions are highlighted through real-life case studies and interviews with sector experts. For each of the macro objectives, a significant performance improvement can be achieved through actions of either small or near-zero cost, such as focusing on user behavioural change and implementing controls to manage the efficient use of resources. The potential of the action packages is maximised when the macro objectives are considered, applying a life-cycle approach, early in the design phase of a building.

Executive summary

Objectives of this report

This report aims to provide qualitative and quantitative evidence regarding the costs and benefits associated with working towards enhancing the sustainability of the European building stock.

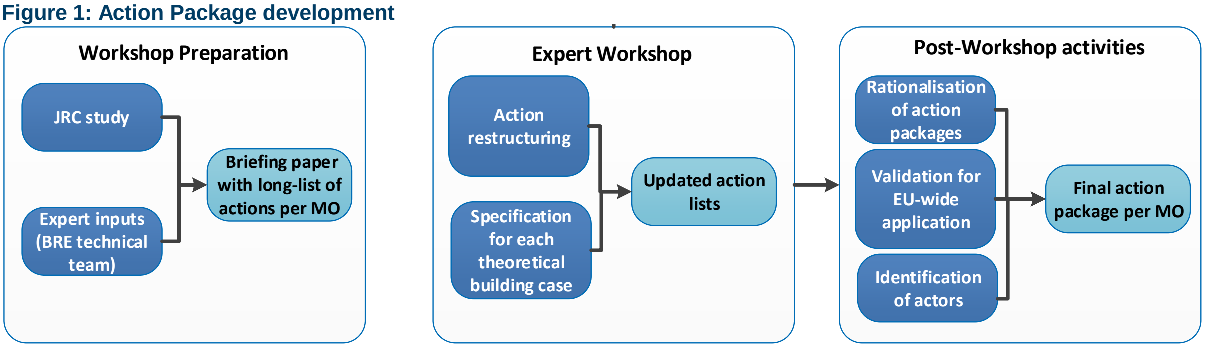
The need for a common EU approach to assess the environmental performance of buildings has been identified in the European Commission's 2014 Communication on Resource Efficiency Opportunities in the Building Sector. A study by DG ENV and DG GROW, with the technical support of DG JRC-IPTS, identified a set of six macro objectives for the environmental performance of buildings. In the following chapters, these six macro objectives are addressed:

- ✓ Macro objective 1: Greenhouse gas emissions from building life cycle energy use.
- ✓ Macro objective 2: Resource efficient and circular material life cycles.
- ✓ Macro objective 3: Efficient use of water resources.
- ✓ Macro objective 4: Healthy and comfortable spaces.
- ✓ Macro objective 5: Adaptation and resilience to climate change.
- ✓ Macro objective 6: Optimised life cycle cost and value

Methodological brief

For each of these macro objectives, a suggested action package has been developed to include widely applicable actions addressing the needs of both residential and office buildings. These actions represent simple-to-apply, cost-efficient actions that can be applied to both the existing as well as to the prospective building stock in order to work towards the macro objectives. As presented in Figure 1, the action packages were developed through literature research[1] and calibrated through a series of six workshops with a group of sector experts in each of the subject areas. An important consideration in the development of the action packages has been their applicability in different climatic and geographical contexts. Therefore, building experts across the EU have been approached to validate these action packages.

Figure 1: Action Package development



An extensive literature review was used to identify actual cases with measured costs and benefits of implementing the actions of the action packages.

1 Examples of real-life case studies are highlighted in blue text in the subsequent chapters.

Sector experts were additionally interviewed to verify initial findings and to complement the factual basis where quantitative evidence was lacking. Finally, where the lack of evidence persisted, or the registered impacts of the different actions where not possible to straightforwardly disaggregate, this initial set of actions has been consolidated to a more coherent set as presented in the section devoted to each macro objective.

Macro Objective 1 - Greenhouse gas emissions from building life cycle energy use

Europe has set the goal to limit climate change by first reducing the greenhouse gas (GHG) emissions by 20%, and increasing renewable energy by 20% and becoming 20% more energy efficient by 2020 compared to the situation in 1990. In this context, an action package has been developed for the first macro objective comprising of five widely applicable actions to reduce GHG emissions. Although the macro objective itself covers the life cycle energy use of buildings (i.e. operational and embodied energy), the scope of the macro objective within this study is limited to the operational energy as embodied energy is examined in Macro Objective 2. Energy consumption can be used as a proxy indicator when discussing the benefits of reducing greenhouse gas emissions because it is a straightforward measurement that does not depend on the energy mix of the grid to which a building is connected, thus facilitating comparisons across the EU. This energy consumption indicator can then be easily translated to GHG emissions reduction for the specific Member States taking into account their specific energy sources and electricity mixes.

A set of five actions have been identified to improve energy efficiency, with the overall aim being to reduce GHG emissions. These include:

- ✓ Installing energy efficient lighting;
- ✓ Installing HVAC2 and lighting controls;
- ✓ Verifying the build/installation quality;
- ✓ Implementing operational performance measures;
- ✓ Installing efficient heat pumps (forward-looking action when considering large-scale implementation).

The highest potential to reduce the energy consumption of the European building stock lies in measures for existing buildings and especially the oldest ones. Actions with the high reduction potential include the implementation of HVAC and lighting control systems, which can result in an energy consumption reduction of up to 20%. This potential can be unlocked with costs as low as € 3/m² for larger office buildings. When complemented with other quick-win actions such as implementing energy efficient lighting, system commissioning and, in the near future, installation of energy efficient heat pumps for heating and cooling, the GHG emissions reduction potential increases even more. It is expected that the energy consumption reduction potential through this action package is generally going to be similar across Europe. Nevertheless, there will be differences in the total GHG emission reduction due to the specific energy sources on which the different grids across Europe operate.

2 Heating, ventilation and air conditioning

Macro Objective 2 – Resource efficient material

Resource efficiency, as viewed from a life-cycle approach, is generally considered as an essential element on the road towards a circular economy.

Resource efficiency therefore does not only refer to efficient use of resources, but encompasses minimising the environmental impact from the use of resources, bringing within its scope also waste prevention and recycling efforts, and more sustainable production and consumption patterns, to produce "*more from less*"[3].

The aim of this second macro objective for the building sector is to increase resource efficiency during the life cycle of buildings through actions accounting for the differences in building culture across Europe. The identified actions for the second macro objective include:

- ✓ Low overall environmental impact of construction materials;
- ✓ Durable, low-maintenance materials for high risk elements;
- ✓ Prolonging building service-life with preventative maintenance strategies;
- ✓ Replacement of primary materials with secondary materials through increased reuse and recycling.

As each building is unique in terms of design, material composition and construction methods, there are very few, if any, straightforward solutions that can be applied across the board to increase the building performance. The main change that is required is the adjustment of the thinking and action processes throughout all phases of the building life cycle to incorporate a Life Cycle Assessment (LCA) of resource efficiency. Any action taken in that respect should therefore be put in the specific building context, especially the planning and design process and can only be specified on a case-by-case basis.

Although comparable specific data presenting the cost and benefits of enhancing efficient material usage in the building sector is limited and usually very case specific, a general potential of reducing carbon embodied emissions in construction materials is reported to be around 25%. Case studies analysed from the Netherlands, France, Italy and Denmark confirmed this potential. Literature and expert judgements moreover indicate a significant potential to increase this number in a financially affordable way if LCA principles are applied from the design phase. However, a more detailed assessment of costs and benefits across Europe requires harmonised LCA to become common practice in the design process. Nevertheless, the additional costs for selecting more environmentally friendly materials seem to be negligible for new buildings when these are considered during the design stage rather than incorporated later in the construction life-cycle.

Macro Objective 3 - Efficient use of water resources

With increasing droughts, reducing river flows, lowered lake and groundwater levels, and drying up of wetland, Europe is challenged to use water more efficiently. Buildings, accounting for the main consumption of water from supply systems[4], offer significant scope to tackle water scarcity through achieving more efficient water usage.

3 https://www.eea.europa.eu/themes/waste/resource-efficiency/resource-efficiency
4 http://ec.europa.eu/environment/water/quantity/pdf/Water%20Performance%20of%20Buildings_Study2009.pdf

An action package has been designed to reduce water consumption including a number of "quick-win actions" to improve water efficiency in buildings including:

- ✓ Installing water efficient equipment;
- ✓ Installing rainwater harvesting systems;
- ✓ Installing building leak detection systems and conducting water audits;
- ✓ Installing smart meters;
- ✓ Providing guidance and training to operators and occupants.

Quick-win actions in residential and office buildings - such as water efficient equipment, rainwater harvesting systems, leakage prevention, or smart meters and training - carry significant potential to reduce water consumption across Europe, with the potential to make recent buildings 30% and older buildings 50% more efficient with a relatively small investment. Although this potential would not be feasible in all places, as local conditions differ, these actions are in most cases economically attractive as well. Installing water efficient equipment generally has a payback period of only one to two years, offering a quick-win solution to reduce water consumption.

Macro Objective 4 - Healthy and comfortable spaces

We typically spend up to 90% of our time indoors, either at home, work or during other activities[5,6]. Air quality inside public and private buildings is an essential determinant of health and well-being according to this macro objective. Uncomfortable high temperatures, reduced ventilation and poor air quality cause distraction from work and can lead to symptoms such as headaches, difficulty to concentrate or think clearly[7]. In order to meet carbon reduction goals, future buildings will be increasingly well insulated and increasingly air-tight. The increased focus on air-tight building envelopes will require an increased attention for ventilation measures and VOC source control to ensure good indoor air quality, thus on the well-being of workers and building occupants for both new and refurbished buildings[8].

An action package has been developed to include actions focused on reducing the concentrations of hazardous substances emitted from construction materials, furnishing and occupant behaviour, such as space heating and cooking. Notably, these actions focus on reduction of VOCs although they also lead to reduction of the concentration of other pollutants and substances such as radon, NO_2, CO, benzene, formaldehydes, particles, CO_2, heavy metals and asbestos:

- ✓ Installation of health-based ventilation rates;
- ✓ Application of low VOC emitting building materials;
- ✓ Building flush out and cleaning of ventilation systems prior to building occupation.

Cases from Europe and the US regarding improved indoor air quality in office buildings have been found to bring productivity gains of up to 11% due to improved ventilation rates, dedicated delivery of fresh air to the workstation, and reduced levels of pollutants. Notably, taking actions towards improving ventilation rates and VOC source control in office environments, comes at investment and operation

5 European Environment Agency, https://www.eea.europa.eu/signals/signals-2013/articles/indoor-air-quality [retrieved 29/05.2017]
6 JRC, http://indoor-air-quality.jrc.ec.europa.eu/, retrieved 26/5/2017
7 P. Wargocki, O. Seppanen (editors), J. Andersson, D. Clements-Croome, K. Fritzner & S. O. Hanssen (2006), Indoor Climate and Productivity in Offices – How to integrate productivity in life-cycle cost analysis of building services, Guidebook No. 6, by REHVA – Federation of European Heating and Air-conditioning Associations.
8 H. B. Awbi (2015), Indoor air quality in UK homes and its impact on health, School of built environment, University of Reading

costs that are quickly offset by the financial benefits of improved employee health, performance and productivity, with an achieved reduction of sick leave potentially as high as 35%.
For residential buildings, natural ventilation comes at low investment and operational costs, as it requires minor adjustments and mainly behavioural change, while relevant benefits relate to the improvement of residents' health conditions. Finally, pre-occupancy building flush-out can contribute to the above at a relatively low cost.

Macro Objective 5 - Resilience to climate change

Looking at the second half of this century, a large part of the European building stock is not well equipped to cope with a changing climate. Old buildings lack an efficient thermal envelop and new air-tight buildings often lack sufficient ventilation and, hence, both are seen as vulnerable parts of the building stock. Specifically, up to 25% of the current building stock of non-residential buildings (including office buildings) will need extensive retrofitting to effectively manage the increasing temperatures or otherwise face unsustainable increases in energy bills. Further, as heatwaves are associated with increases in mortality rates and other negative health impacts, and uncomfortably warm office temperatures can greatly affect productivity, failing to adapt building stock can result in an increased severity of these impacts as the climate change phenomenon unravels.

With the time horizon for this macro objective set in the long term and, regardless of the location and existing condition of a building, "quick-win" actions can make a substantial difference in improving thermal comfort. These include focus on:
- ✓ Minimising heat gains;
- ✓ Implementing energy efficient cooling options (including increased ventilation rates and using energy efficient heat pumps for HVAC[9] in the long term).

The effectiveness of both actions is moreover maximised when providing guidance and training to achieve behavioural change.

Combinations of these actions provide the potential of eliminating 30 to 100% of the overheating duration in a building (depending on the specific building) resulting in an improvement of thermal comfort and residents' health, and/or cost savings for avoiding active cooling. For office buildings, improved solar shading (costing approx. € 10 to 50/m^2) would suffice for the less impacted areas and/or for the first years of the mitigation. This can be complemented with a central mechanical ventilation system for slightly more impacted cases with systems that can cost between € 40/m^2 for new buildings and € 200/m^2 for complex fitting in existing structures. Nevertheless, as already common practice in Southern Europe, combining this with a cooling system is unavoidable for the most impacted buildings. Despite the high costs, the significant expected productivity gains (1-3%) brings the payback period to between 1 and 6 years.

9 Heating, ventilation and air conditioning.

Macro Objective 6 – Optimised life cycle cost and value

The life cycle costs of buildings are often higher than necessary because too often solutions are selected based solely on investment costs. In order to maximise the life-cycle value of buildings, it is important to look further than the investment cost to ensure a cost effective building operation as well as a good future market value. Durable materials, which require a higher investment cost, for example, may still be preferred from a life cycle cost perspective because they require lower operational costs - due to less frequent replacements that are needed and/or due to lower maintenance costs.

Therefore, in the context of this macro objective for the building sector "*optimise life cycle cost and valu*e", four actions are proposed to reduce the life cycle costs representing the "low-hanging fruits" that can be easily and effectively implemented for the majority of the building stock. To discuss the costs and benefits related to this macro objective, the additional investment cost and the total life cycle cost savings are respectively seen as indicators. As total life-cycle costs are not commonly calculated for a building, improvements in that respect are more often replaced by more specific cost savings such as reduced energy bills or reduced maintenance costs.

The four actions identified to improve life cycle cost in buildings include:

- ✓ Use of durable, low-maintenance materials (for high risk elements);
- ✓ Installation of and user guidance for the operation of HVAC control systems;
- ✓ User guidance/training and implementing preventative maintenance strategies to prolong the service life of building materials;
- ✓ Designing services and service routes for ease of access for maintenance and refurbishment.

Implementing such actions can result in reductions in energy bills of up to 20% for existing buildings and up to 5% for new-builds. In addition, user guidance and training and design strategies to simplify maintenance and replacements during the building life span have a high potential to reduce costs, although these savings were not yet quantified in the cases analysed. Overall, the combination of building measures and user guidance can easily lead to a reduced life cycle cost of a building.

Résumé analytique

Objectifs de ce rapport

Ce rapport vise à fournir des preuves qualitatives et quantitatives sur le coût et les avantages liés à l'amélioration de la durabilité du parc immobilier européen.

Le Rapport 2014 sur les possibilités de durabilité dans le secteur du bâtiment de la Commission européenne met en évidence la nécessité d'une approche commune de l'UE afin d'évaluer la performance environnementale des bâtiments. Une étude menée par les directions générales de l'environnement et du développement, assistées par des experts de la direction générale de l'Institut de prospective technologique du CCR (JRC-IPTS), a permis de définir six objectifs macro-environnementaux relatifs au rendement énergétique des édifices. Les six objectifs macro-environnementaux évoqués dans les chapitres suivants traitent des points suivants:

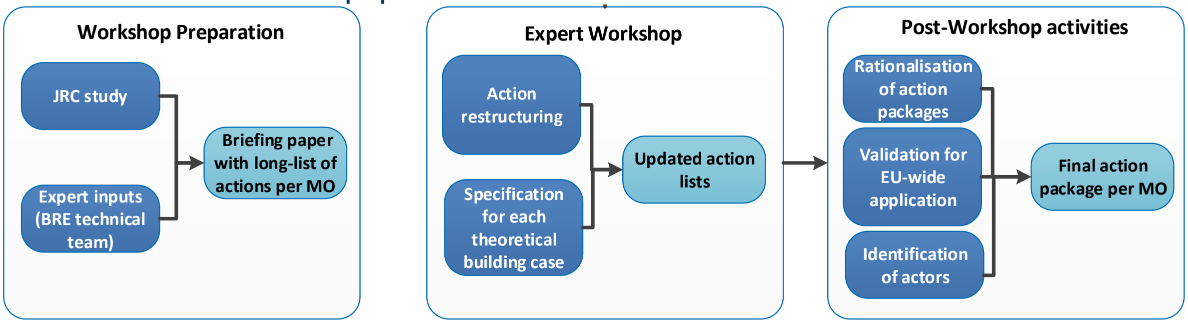
- ✓ Objectif macro-environnemental 1 : Émissions de gaz à effet de serre liées à la consommation énergétique au cours du cycle de vie des bâtiments
- ✓ Objectif macro-environnemental 2 : Cycles de vie des matériaux circulaires et durables
- ✓ Objectif macro-environnemental 3 : Utilisation rationnelle des ressources hydrauliques
- ✓ Objectif macro-environnemental 4 : Espaces sains et agréables
- ✓ Objectif macro-environnemental 5 : Adaptation et résilience vis-à-vis du changement climatique
- ✓ Objectif macro-environnemental 6 : Optimisation du coût et de la valeur du cycle de vie

Notes méthodologiques

Pour tous ces objectifs macro-environnementaux, un ensemble de mesures a été proposé, y compris des mesures applicables à grande échelle qui répondent à la fois aux besoins des bâtiments administratifs et des résidences. Il s'agit de mesures économiques et faciles à mettre en place, qui peuvent s'appliquer aux édifices existants ainsi qu'aux bâtiments futurs en vue d'atteindre les objectifs macro-environnementaux. Tel que présenté dans le Schéma 1, l'ensemble des mesures a été proposé suite à des recherches documentaires[10] et étalonné dans le cadre d'une série de six réunions avec un groupe d'experts œuvrant dans chaque corps de métier du secteur. L'applicabilité de l'ensemble des mesures proposées dans des contextes climatiques et géographiques différents a constitué un élément important. Des experts en bâtiment au sein de l'UE ont donc été consultés afin de valider cet ensemble de mesures.

10 Les exemples d'études de cas réels apparaissent en bleu dans les chapitres subséquents.

Schéma 1: Ensemble de mesures proposées



Un examen détaillé des documents a permis d'identifier les cas réels ainsi que d'évaluer les coûts et avantages de la mise en œuvre des mesures faisant partie de l'ensemble des mesures. De plus, les experts dans le secteur ont été interrogés afin de valider les premiers résultats et d'appuyer les faits en cas d'absence de preuves quantitatives. Enfin, en cas de preuves toujours manquantes ou d'impacts déclarés suite aux différentes mesures, dans la mesure où il est tout simplement impossible de les atténuer, ce premier ensemble de mesures deviendra un ensemble plus cohérent, tel que présenté dans la section dédiée à chaque objectif macro-environnemental.

Objectif macro-environnemental 1 - Émissions de gaz à effet de serre liées à la consommation énergétique au cours du cycle de vie des bâtiments

L'Europe s'est fixée pour objectif de limiter le changement climatique en réduisant tout d'abord les émissions de gaz à effet de serre de 20 %, et en augmentant la part des énergies renouvelables de 20 % pour devenir 20 % plus rentable d'un point de vue énergétique d'ici 2020 par rapport à la situation en 1990. Dans ce contexte, un ensemble de mesures a été mis au point pour l'objectif macro-environnemental 1, dont 5 mesures applicables à grande échelle afin de réduire les émissions de gaz à effet de serre. Bien que l'objectif macro-environnemental proprement dit porte sur la consommation énergétique au cours du cycle de vie des bâtiments (par exemple, l'énergie grise utilisée pour le fonctionnement), le champ d'application de l'objectif macro-environnemental dans le cadre de la présente étude se limite à l'énergie utilisée pour le fonctionnement du fait de énergie incorporée est examinée dans Macro Objectif 2. La consommation énergétique peut servir d'indicateur supplétif lorsque les avantages de réduire les émissions de gaz à effet de serre sont évoqués, car il s'agit d'une mesure simple qui ne dépend pas du bouquet énergétique du réseau auquel un bâtiment est relié, ce qui facilite les comparaisons au sein de l'UE. Cet indicateur de consommation énergétique peut alors être facilement converti en émissions de gaz à effet de serre pour certains États membres en prenant en compte certaines de leurs sources énergétiques et les bouquets d'électricité.

Cinq mesures ont été identifiées afin d'améliorer le rendement énergétique, toutes étant destinées à réduire les émissions de gaz à effet de serre. Ces 5 mesures comprennent:

- ✓ L'installation d'un éclairage basse consommation ;
- ✓ L'installation de systèmes de CVC[11]et de commandes d'éclairage ;
- ✓ La vérification de la qualité de l'installation/bâtiment ;
- ✓ La mise en place de mesures de rendement opérationnel ;
- ✓ L'installation de pompes à chaleur performantes (mesure prospective avant de décider d'une mise en œuvre à grande échelle).

11 Chauffage, ventilation et climatisation

Réduire de manière conséquente la consommation énergétique du parc immobilier en Europe repose sur des mesures destinées aux bâtiments existants, et notamment les plus anciens. Les mesures qui permettent une diminution importante prévoient la mise en place de systèmes de CVC et de commandes d'éclairage qui peuvent mener une réduction de la consommation énergétique pouvant atteindre 20 %. Il est possible d'améliorer ce potentiel en ayant des coûts les plus bas possible, soit 3 EUR/m² pour les bâtiments administratifs les plus grands. Si nous rajoutons d'autres mesures à gains immédiats, telles que la mise en place d'éclairages basse consommation, la mise en service des systèmes et, prochainement, l'installation de pompes à chaleur économiques pour le chauffage et la climatisation, il est d'autant plus probable que les émissions de gaz à effet de serre diminuent.
Cet ensemble de mesures est susceptible de permettre la réduction de la consommation énergétique qui, d'une manière générale, sera assimilée à tous les pays européens. Néanmoins, des différences dans la réduction totale des émissions de gaz à effet de serre apparaitront en raison d'autres sources énergétiques exploitées par les différents réseaux en Europe.

Objectif macro-environnemental 2 – Matériaux durables

La durabilité, selon une approche de cycle de vie, est, d'une manière générale, considérée comme un élément essentiel pour atteindre une économie circulaire. Par conséquent, la durabilité ne renvoie pas seulement à l'utilisation rationnelle des ressources, mais elle englobe la diminution de l'impact sur l'environnement par le biais de l'utilisation de ressources, en introduisant également dans son champ d'application la prévention des déchets et des efforts en matière de recyclage ainsi que des modes de consommation et de production plus durables, afin de produire « plus avec moins »[12].

Cet objectif macro-environnemental 2 pour le secteur du bâtiment vise à accroître la durabilité pendant le cycle de vie des bâtiments par le biais de mesures qui prennent en compte les différences de politique en matière de construction en Europe. Les mesures définies pour l'objectif macro-environnemental 2 prévoient:

- ✓ Un impact faible sur l'environnement en général des matériaux de construction ;
- ✓ Des matériaux durables et nécessitant peu d'entretien pour les éléments à haut risque ;
- ✓ Le prolongement du cycle de vie des bâtiments grâce à la mise en place de stratégies d'entretien préventives ;
- ✓ Le remplacement des matières premières par des matières secondaires grâce au développement de la réutilisation et du recyclage.

Chaque bâtiment étant unique en termes de conception, composition des matériaux et méthodes de construction, très peu de solutions simples, le cas échéant, peuvent s'appliquer à tous les édifices qui permettent d'accroître la performance des édifices. Le principal changement qui s'impose est de modifier les processus de réflexion et d'action tout au long des étapes du cycle de vie des bâtiments en se basant sur une évaluation du cycle de vie (ECV) de la durabilité. Toute mesure prise à cet égard doit alors faire partie du cadre particulier des bâtiments, notamment le processus de planification et de conception, et peut uniquement être définie qu'au cas par cas.

Bien que certaines données comparables indiquant le coût et les avantages d'améliorer l'utilisation de matériaux performants dans le secteur du bâtiment sont limitées et généralement très spécifiques, la

12 https://www.eea.europa.eu/themes/waste/resource-efficiency/resource-efficiency

possibilité de réduire de manière globale les émissions de carbone dans les matériaux de construction doit être d'environ 25 %. Les études de cas menées depuis les Pays-Bas, la France, l'Italie et le Danemark ont confirmé cette éventualité. Par ailleurs, les experts et chercheurs pensent que ce chiffre pourrait augmenter sensiblement d'une façon abordable du point de vue financier si les principes d'évaluation du cycle de vie sont appliqués à partir de la phase de conception. Cependant, une évaluation détaillée des coûts et avantages en Europe nécessite une ECV harmonisée afin que cela devienne une pratique courante lors du processus de conception. Néanmoins, pour ce qui est des nouveaux bâtiments, les coûts supplémentaires relatifs à la sélection de matériaux plus respectueux de l'environnement semblent être minimes s'ils sont pris en compte au cours de la phase de conception plutôt qu'ultérieurement, au cours du cycle de vie de la construction.

Objectif macro-environnemental 3 - Utilisation rationnelle des ressources hydrauliques

Avec l'augmentation des sécheresses, la diminution du débit fluvial, l'abaissement du niveau des lacs et nappes souterraines et le tarissement des zones humides, l'Europe prévoit d'utiliser l'eau d'une manière plus rationnelle. Les bâtiments, qui représentent la consommation d'eau principale des systèmes d'approvisionnement[13], offrent de nombreuses possibilités de lutter contre la rareté en utilisant l'eau de manière plus rationnelle.

L'ensemble des mesures est destiné à diminuer la consommation d'eau, dont un certain nombre de « mesures à gains immédiats » visant à améliorer l'utilisation rationnelle de l'eau des bâtiments, y compris :

- ✓ L'installation de matériel à faible consommation d'eau ;
- ✓ L'installation de récupérateurs d'eau de pluie ;
- ✓ L'installation de systèmes de détection de fuite dans les bâtiments et la vérification des canalisations ;
- ✓ L'installation de compteurs intelligents;
- ✓ La fourniture d'instructions et de formations aux opérateurs et occupants.

Pour illustrer cela, de nombreuses études de cas sont présentées ci-dessous.

Les mesures à gains immédiats pour les résidences et bâtiments administratifs, telles que du matériel à faible consommation d'eau, des récupérateurs d'eau de pluie, la prévention de fuites d'eau ou des compteurs intelligents et des formations permettent de réduire de manière importante la consommation d'eau en Europe, avec la possibilité de faire 30 % d'économies sur les nouveaux bâtiments et 50 % sur les édifices plus anciens via un investissement relativement modeste. Bien que ces mesures ne pourront pas être mises en place pour tous les bâtiments, dans la mesure où les conditions sur place diffèrent, elles sont également intéressantes d'un point de vue économique dans la plupart des cas. En général, l'installation de matériel à faible consommation d'eau ramène la période de remboursement à entre 1 et 2 ans uniquement, offrant ainsi une solution à gains immédiats qui permet de réduire la consommation d'eau.

13 http://ec.europa.eu/environment/water/quantity/pdf/Water%20Performance%20of%20Buildings_Study2009.pdf

Objectif macro-environnemental 4 - Espaces sains et agréables

Habituellement, nous passons jusqu'à 90 % de notre temps à l'intérieur, soit à la maison, soit au travail, soit au cours d'autres activités[14,15]. Selon cet objectif macro-environnemental, la qualité de l'air au sein des bâtiments publics et privés est un facteur important de santé et de bien-être. Des températures élevées désagréables, une ventilation réduite et une mauvaise qualité de l'air peuvent être gênantes dans le travail et provoquer des symptômes tels que des maux de tête ou une difficulté à se concentrer ou à bien réfléchir[16]. Afin d'atteindre les objectifs en matière de réduction de carbone, l'isolation et l'étanchéité des futurs bâtiments vont s'améliorer davantage.

L'accent mis sur l'étanchéité des matériaux extérieurs des bâtiments exigera une attention accrue vis-à-vis des systèmes de ventilation et des contrôles des sources de COV afin de garantir une bonne qualité de l'air à l'intérieur, ainsi que sur le bien-être des ouvriers et des occupants des bâtiments pour les nouveaux édifices et les bâtiments rénovés[17].

Un ensemble de mesures a été mis en place pour intégrer des mesures ciblant la réduction des concentrations de substances dangereuses émises de matériaux de construction, la rénovation et le comportement des occupants, telles que le système de chauffage des bâtiments et les installations de cuisson. Ces mesures mettent notamment l'accent sur la réduction des COV, bien qu'elles prévoient également la diminution de la concentration d'autres polluants et substances tels que le radon, le dioxyde de carbone (NO_2), le monoxyde de carbone (CO), le benzène, le formaldéhyde, les particules, le dioxyde de carbone (CO_2), les métaux lourds et l'amiante :

- ✓ La mise en place de taux de ventilation basés sur la santé ;
- ✓ L'utilisation de matériaux de construction à faible émission de COV ;
- ✓ La purge et l'entretien des systèmes de ventilation d'avant d'occuper le bâtiment.

Des cas identifiés en Europe et aux États-Unis concernant l'amélioration de la qualité de l'air intérieur dans les bâtiments administratifs ont réalisé des gains de productivité pouvant atteindre 11 % grâce à de meilleurs taux de ventilation, de diffusion d'air frais réservée aux postes de travail et de réduction des niveaux des polluants. Les mesures prises par rapport à l'amélioration des taux de ventilation et le contrôle des sources COV au sein des bâtiments administratifs permettent notamment des coûts d'investissement et d'exploitation que les avantages financiers liés à l'amélioration sur la santé, à la performance et à la productivité des employés peuvent rapidement compensés, ainsi qu'une diminution des arrêts maladie susceptible d'être supérieure à 35 %. Concernant les résidences, la ventilation naturelle implique des coûts d'investissement et d'exploitation modestes, car elle demande des réglages mineurs et surtout un changement de comportement, tant que les avantages pertinents sont liés à l'amélioration de l'état de santé des résidents. Au final, purger les bâtiments avant leur occupation peut contribuer à cette amélioration moyennant un coût relativement bas.

14 Agence européenne pour l'environnement, https://www.eea.europa.eu/signals/signals-2013/articles/indoor-air-quality [extrait datant du 29/05/2017]
15 JRC, http://indoor-air-quality.jrc.ec.europa.eu/, extrait en date du 26/5/2017
16 P. Wargocki, O. Seppanen (rédacteurs), J. Andersson, D. Clements-Croome, K. Fritzner & S. O. Hanssen (2006), Climat intérieur et productivité des bâtiments administratifs – Comment intégrer la productivité dans l'analyse du coût du cycle de vie des équipements techniques du bâtiment, Manuel n° 6 de REHVA – Federation of European Heating and Air-conditioning Associations.
17 H. B. Awbi (2015), La qualité de l'air à l'intérieur des résidences britanniques et son impact sur la santé, École supérieure de l'environnement bâti, Université de Reading

Objectif macro-environnemental 5 - Résilience vis-à-vis du changement climatique

Si l'on examine la deuxième moitié de ce siècle, une bonne partie du parc immobilier européen n'est pas bien conçue pour faire face à un changement climatique.
Les anciens bâtiments ne sont pas assez bien isolés et les nouveaux édifices étanches ne sont pas suffisamment ventilés et sont donc considérés comme étant des éléments vulnérables du parc immobilier. Jusqu'à 25 % du parc immobilier actuel composé de bâtiments non résidentiels (y compris les bâtiments administratifs) nécessiteront notamment d'une remise en état importante afin de faire face de manière efficace à des températures en augmentation ou sinon à des factures énergétiques qui « explosent ». Les vagues de chaleur étant également liées aux hausses du taux de la mortalité et aux autres impacts négatifs sur la santé, et avec des températures élevées gênantes au sein des bâtiments administratifs pouvant impacter considérablement la productivité, ne pas adapter le parc immobilier peut entraîner un accroissement de la gravité de ces impacts tant que le phénomène de changement climatique n'est pas résolu.

Avec le délai pour cet objectif macro-environnemental fixé à long terme et sans tenir compte de l'emplacement et des conditions existantes d'un bâtiment, des mesures « à gains immédiats » peuvent permettre d'améliorer considérablement le confort thermique. Ces mesures mettent l'accent sur:

- ✓ La diminution des gains de chaleur ;
- ✓ La mise en place de solutions de refroidissement écoénergétiques (y compris la hausse des taux de ventilation et l'utilisation de pompes à chaleur à bon rendement énergétique pour le chauffage, la ventilation et la climatisation18 à long terme).

L'efficacité de ces 2 mesures est de surcroît maximisée si des instructions et des formations sont données dans le but d'un changement de comportement.

L'association de ces mesures permet d'éliminer la période de surchauffe de 30 à 100 % au sein d'un bâtiment (selon le type d'édifice), d'où une amélioration du confort thermique et de la santé des résidents, et/ou des économies afin d'éviter le refroidissement actif. Pour les bâtiments administratifs, l'amélioration de la protection solaire (qui coûte environ entre 10 et 50 EUR/m^2) suffirait pour les zones les moins impactées et/ou pendant les premières années de la limitation. Le système de refroidissement peut être complété par un système de ventilation mécanique centralisé pour des cas un peu plus impactés et des systèmes pouvant coûter entre 40 EUR/m^2 pour les nouveaux édifices et 200 EUR/m^2 pour les structures existantes à la conception complexe. Néanmoins, comme c'est déjà le cas en Europe du Sud, l'association d'un système de ventilation avec un système de refroidissement est inévitable pour les bâtiments les plus impactés. Malgré les coûts élevés, les importants gains de productivité escomptés (entre 1 et 3 %) ramènent la période de remboursement à entre 1 et 6 ans.

18 Chauffage, ventilation et climatisation

Objectif macro-environnemental 6 – Optimisation du coût et de la valeur du cycle de vie

Les coûts du cycle de vie des bâtiments sont souvent plus élevés que ce qui est nécessaire, parce que trop souvent des solutions sont choisies uniquement en fonction des coûts d’investissement. Afin de maximiser la valeur du cycle de vie des bâtiments, il convient d’aller au-delà des coûts d’investissement afin de garantir une exploitation économique des bâtiments ainsi qu’une bonne valeur de marché future. Par exemple, les matériaux durables qui exigent des coûts d’investissement plus élevés sont susceptibles de demeurer les matériaux privilégiés du point de vue du coût de leur cycle de vie, parce qu’ils requièrent des coûts d’exploitation moindres en raison de la nécessité moins fréquente de les remplacer et/ou de leurs coûts d’entretien plus bas.

Par conséquent, dans le cadre de cet objectif macro-environnemental pour le secteur de la construction « *optimiser le coût et la valeur du cycle de vie* », 4 mesures sont proposées afin de diminuer les coûts du cycle de vie qui représentent les « solutions de facilité » pouvant être mises en place facilement et correctement pour la majorité du parc immobilier. Pour examiner les coûts et les avantages liés à cet objectif macro-environnemental, les coûts d’investissement supplémentaires et l’ensemble des économies en termes de coût du cycle de vie sont considérés de manière respective comme des indicateurs. Le coût total du cycle de vie n’étant pas souvent calculé pour un bâtiment, les améliorations à cet égard sont plus souvent remplacées par plus d’économies financières spécifiques telles que la diminution des factures énergétiques ou des coûts d’entretien.

Les 4 mesures définies pour améliorer le coût du cycle de vie des bâtiments prévoient :

- ✓ L’utilisation de matériaux durables et nécessitant peu d’entretien (pour les éléments à haut risque) ;
- ✓ L’installation et des instructions pour l’utilisation des systèmes de contrôle CVC ;
- ✓ Des instructions/formations et la mise en place de stratégies d’entretien préventives afin de prolonger le cycle de vie des matériaux de construction ;
- ✓ Des services d’étude et des méthodes à suivre pour la mise en service de façon à faciliter l’entretien et la remise en état.

La mise en place, telle que des mesures, peut permettre la diminution du montant des factures énergétiques pouvant atteindre 20 % pour les bâtiments existants et 5 % pour les nouveaux édifices. En outre, des instructions pour l’utilisation, des formations et des stratégies de conception afin de simplifier l’entretien et les remplacements au cours du cycle de vie des bâtiments sont susceptibles de réduire vraiment les coûts, bien que ces économies n’aient pas encore été quantifiées dans les cas analysés. En général, la combinaison des mesures relatives aux bâtiments et les instructions pour l’utilisation peuvent facilement conduire à une diminution du coût du cycle de vie d’un édifice.

Introduction

Objectives of this report

This report aims to provide qualitative and quantitative evidence regarding the costs and benefits associated with working towards enhancing the sustainability of the European building stock.

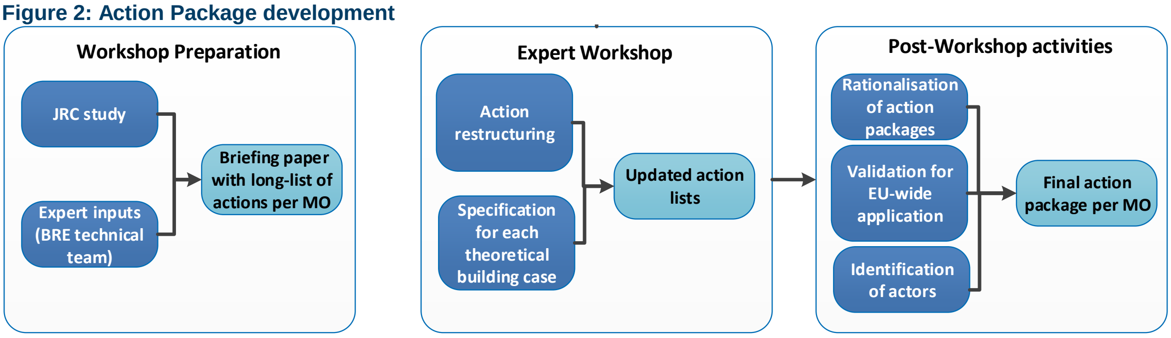
The need for a common EU approach to assess the environmental performance of buildings has been identified in the European Commission's 2014 Communication on Resource Efficiency Opportunities in the Building Sector. A study by DG ENV and DG GROW, with the technical support of DG JRC-IPTS, identified a set of six macro objectives for the environmental performance of buildings. In the following chapters, these 6 macro objectives are addressed:

- ✓ Macro objective 1: Greenhouse gas emissions from building life cycle energy use.
- ✓ Macro objective 2: Resource efficient and circular material life cycles.
- ✓ Macro objective 3: Efficient use of water resources.
- ✓ Macro objective 4: Healthy and comfortable spaces.
- ✓ Macro objective 5: Adaptation and resilience to climate change.
- ✓ Macro objective 6: Optimised life cycle cost and value.

Methodological brief

For each of these macro objectives, a suggested action package has been developed to include widely applicable actions addressing the needs of both residential and office buildings. These actions represent simple-to-apply, cost-efficient actions that can be applied to both the existing as well as to the prospective building stock in order to work towards the six macro objectives. As presented in Figure 2, the action packages were developed through literature research[19] and calibrated by means of a series of six workshops with a group of experienced experts in each of the subject areas. An important consideration in the development of the action packages has been their applicability in different climatic and geographical contexts. This element has been further pursued by approaching building experts across the EU for validation[20]. Both groups of experts are listed in Annex I.

Figure 2: Action Package development



19 Examples of real-life case studies are highlighted in blue text in the subsequent chapters.
20 Highlights of expert inputs are indicated in orange text boxes in the subsequent chapters.

An extensive literature review followed in order to identify actual cases that have measured the costs and benefits of implementing the actions of the action packages. Interviews with sector experts were used to verify initial findings but also to complement these when quantitative evidence was lacking. An overview of data sources for each macro objective is found in Annex II. Finally, where the lack of evidence persisted, or the registered impacts of the different actions where not possible to straightforwardly disaggregate, this initial set of actions has been consolidated to a more coherent set as presented in the section devoted to each macro objective.

For some of the macro objectives, a rather complete overview of the baseline situation across the EU has been sketched based on existing statistics. These are given in Annex III and Annex IV regarding energy and water consumption. Finally, Annex V presents the major residential and office building stock segments in the EU. This helps to assess the level of applicability of the action packages.

Macro Objective 1 - Greenhouse gas emissions from building life cycle energy use

Europe has set the goal to limit climate change by first reducing the greenhouse gas (GHG) emissions by 20%, and increasing renewable energy by 20% and becoming 20% more energy efficient by 2020 compared to the situation in 1990. In this context, an action package has been developed for the first macro objective comprising of five widely applicable actions to reduce GHG emissions. Although the macro objective itself covers the life cycle energy use of buildings (i.e. operational and embodied energy), the scope of the macro objective within this study is limited to the operational energy as embodied energy is examined in Macro Objective 2. Energy consumption can be used as a proxy indicator when discussing the benefits of reducing greenhouse gas emissions because it is a straightforward measurement that does not depend on the energy mix of the grid to which a building is connected, thus facilitating comparisons across the EU. This energy consumption indicator can then be easily translated to GHG emissions reduction for the specific Member States taking into account their specific energy sources and electricity mixes.

Reducing energy consumption in European buildings

The five actions identified to improve energy efficiency in buildings, with the overall aim to reduce the GHG emissions, include:

- ✓ Installing energy efficient lighting;
- ✓ Installing HVAC21 and lighting controls;
- ✓ Verifying the build/installation quality;
- ✓ Implementing operational performance measures;
- ✓ Installing efficient heat pumps (forward-looking action when considering large scale implementation).

The analysis of these actions in existing cases in Belgium, Austria, the United Kingdom and the US proved a savings potential up to 30% in the short-term and up to 60%[22] in the long term in residential buildings. For office buildings, the installation of a control system has a saving potential of up to 20%, while an additional reduction of up to 35% can be achieved when more actions are implemented. This relative reduction is applicable across Europe despite the different energy consumption levels for buildings across the continent.

Energy Efficient Lighting

Installing energy efficient lighting (e.g. LEDs) is an action that leads to considerable energy savings and can be at low cost. Switching to a LED lighting system has the potential to reduce lighting energy use by 90%, leading to a reduction in operational energy consumption by at least 2%.[23] This might

21 Heating, ventilation and air conditioning
22 See Annex 3 on energy consumption across the EU
23 Based on residential house in Belgium.

initially be seen as a relatively small potential, however, when considering that it can be achieved with very low investment costs (less than € 5/m² for changing lamps) and the ease of implementation for this action, it can be realised that this is an obvious quick win applicable to both new and existing buildings. With a payback period of one year, the installation of energy efficient lighting can be a valuable contributor to achieving the aim of reducing energy consumption.

Energy savings by installing energy efficient lighting

A detached house in Neerijse, Belgium, built at the end of 1950's, was renovated in 2008. During the renovation, halogen spots were installed. In order to further reduce the energy use, the owners of the house replaced these halogen spots in the living room and kitchen by LED spots. This intervention led to a reduction in energy cost for lighting of 90%, and the total energy bill was reduced by 2,1%.

HVAC and Lighting Controls

The operational energy use of buildings, and hence their GHG emissions, can be reduced by an important extent when the HVAC and lighting systems are controlled and managed accurately. The analysis of the case studies revealed that old buildings have a higher potential for energy reduction by control systems (between 10-20%) than new buildings (approximately 5%).

Practically, for an old average-sized office building of about 1.500 m² in Belgium, energy savings can be higher than € 600 per year when a full control system is applied. Installing such a control system in an office building (old or new) of 1.500 m² costs approximately € 4.700 indicating a payback period of less than eight years for an old office building. It is expected that the energy savings will be lower for a new office building. However, for new buildings, savings can be up to € 6.300 per year when a controlled variable air volume system is installed instead of a continuous air volume system.[24]

Implementing HVAC and lighting controls in office buildings

In the Legacy Civic Towers in San José (US), energy consumption was reduced by 20%, an annual energy saving of € 7.473 (€ 0,4/m²), by installing a lighting and energy management system. The total cost of this system was € 59.408 (€ 3,2/m²). This cost included the sensor installation, the computer modelling and the energy management system. This control system has a payback period of eight years. [25]

Lars Myhre - ***Norwegian Home Builders' Association, Norway***

'For existing buildings, the heat control systems potential represents around 10-20% of energy savings. New buildings usually have heating control systems (thermostats) and are well insulated. For those, the potential is significantly less (approx. 5%). Both assessments depend highly on user behaviour and settings for thermal comfort preference.'

24 These figures are based on test classrooms at the technology campus in Ghent (Belgium) and are also achieved through the commissioning of the system.

25 Note that the technology used in this example can be seen as technology of advanced new office buildings to date and common practice in new office buildings in the near future in Europe. A case in the US was selected due to data availability.

Verification of the build/installation quality

The gap between design and actual building energy performance has been identified as a recurring issue. Measures to bridge this gap include the verification of the quality of the construction and installation through actions such as thermographic surveys, air-tightness testing and/or improved commissioning of systems.

An analysis of two residential buildings (renovation and new-built) in Belgium showed a reduction of the operational energy use between 9% and 15% by improving the air-tightness. These cases had an additional investment cost of less than 1% to verify the air-tightness level of the building. An additional cost of 6-7% of the investment cost was required to implement the measures to improve the air-tightness. The cost of improving the air-tightness is highly variable as the interventions required depend on the pre-existing condition of the building/results of the air-tightness test.

Air-tightness testing and thermographic surveys

In the low energy renovation of the house in Spiere-Helkijn, Belgium, the energy use for space heating was reduced by 20% (14,5% overall energy use reduction) as a result of improved air-tightness (based on the air-tightness test and thermographic survey). The total cost of implementing the air-tightness measures was €26.790.

The sustainable neighbourhood in Waregem, Belgium, is a pioneering project by Wienerberger consisting of seven attached zero-energy houses built in 2016. The neighbourhood is innovative from its holistic sustainability approach, considering social, ecological and economic aspects. A number of scenarios considering different air-tightness values and window profiles were compared. A medium scenario for air-tightness was chosen, resulting in a reduction of the space heating energy consumption by 12,5% (9,1% overall reduction in energy use) compared to the business-as-usual scenario.

The cases analysed moreover proved that verification of the installation of the technical system for heating, cooling and ventilation has a potential to reduce the total energy consumption of a building. The type of technical system and the type of building however have a big influence on the potential reduction. The case studies underlined the importance of continuous commissioning as the building performance can change over time (e.g. due to ageing of the building envelope or due to renovation measures) and influences the optimal performance of a system. The latter is further described in the subsequent action.

Energy savings through verification and continuous commissioning

In test classrooms on the technology campus in Ghent, Belgium, the fan energy consumption could be reduced by 40% and the ventilation losses by 32% (compared with the situation of constant air volume) by fine-tuning, commissioning and monitoring. The yearly benefit was estimated between € 470 (€ 3,4/m²) and € 1.180 (€ 8,4/m²). The demand control system has a net present value of € 6.600 (€ 47,1/m²) calculated over a 15 year period.

Implementation of operational performance measures

Several measures are available to control and improve the operational energy consumption in new and existing office and residential buildings. Examples can be post occupancy evaluation, guidance/training for operators and/or occupants on correct operation of systems and controls, implementation of a preventative maintenance strategy, and regular energy audits.

Based on the analysis of the residential case studies (Sustainable neighbourhood Waregem, Belgium; Energy renovation Spiere, Belgium) and professional judgement, it is assumed that the improvements implemented after an energy audit will lead to a potential reduction in energy consumption of at least 5%. This potential depends highly on the building performance. In the case study of an old building (Energy renovation Spiere), a reduction of 89% in the energy use for space heating was achieved after an energy audit. Actions taken in an office building (office KU Leuven, Belgium) after an energy audit show a similar energy reduction potential, with a 6% reduction in the total energy consumption or up to 30% reduction in the energy needed for space heating.

Energy audit triggered interventions

Based on an energy audit, the HIVA office building of the KU Leuven, Belgium, was renovated in 2016. The renovation mainly consisted of a replacement of the steel-frame windows. This renovation resulted in an average energy reduction of 30% for space heating compared to the previous two years.

The energy reduction potential from monitoring was studied in several of the cases for both residential buildings and offices, however often the actual reduction was not quantified. In the case study of the sustainable neighbourhood of Waregem, an overall energy reduction of 15-20% is estimated when monitoring the temperature and energy use. It is expected that the impact of monitoring increases when building users have direct access to the monitoring data.

A case study of the Venning in Kortrijk showed the importance of **continuous commissioning**[26] during the operational phase of a building. The importance of supporting and informing the occupants of the building is also highlighted. The potential benefits however, highly depend on the building and the defects occurring. This makes it difficult to estimate benefits quantitatively, although there is agreement about the importance of these measures generally.

The potential of energy savings/performance improvement by continuous commissioning

The social neighbourhood Venning in Kortrijk (Belgium) is a renovation project (within the European ECO-life project) of a social neighbourhood built in the 1960s. Venning is a CO_2-neutral neighbourhood, making use of district heating with a local resource energy supply. During the first year after building completion, in-depth commissioning was executed with the aim to reveal defects in the HVAC system and to identify the key parameters for continuous commissioning in future. The study showed that, even with the initial commissioning and quality assurance tests, there were still important defects (some heat exchangers were not working, reduced ventilation rates occurring) in the first year of use. Although these defects in the technical system led to a lower energy use (due to lower ventilation rates than actually required for a healthy indoor climate, and insufficient heating), the commissioning identified the defects and hence the thermal discomfort and bad indoor air quality could be solved.

26 Continuous Commissioning is an ongoing process to resolve operating problems, improve comfort, and optimize energy use.

Installation of efficient heat pumps

A more future-looking action, referring to the time when energy can be supplied from a low-carbon/decarbonised electricity grid, is extending the use of more efficient heat pumps for hot water production, space heating and/or cooling. There are few limitations to the applicability of heat pumps to new and existing office and residential buildings. The analysis of two case studies where efficient heat pumps were installed showed energy savings of 30% with a similar reduction of GHG emissions when shifting from a fossil fuel based combustion system to a decarbonized electricity supply. These savings are calculated based on energy simulations during the design phase. As several types of heat pumps exist, the required investment cost varies. Case studies show installation costs of around € 12.000 (ca. € 85/m²) for residential buildings and around € 60.000 (ca. € 40/m²) for offices. These costs are expected to drastically decrease in the mid-term future when this technology becomes more widely applied. Additionally, a yearly maintenance cost of about 1% of the investment cost should be accounted for.

Energy efficient heat pumps

SD Worx is a 1.350 m² private low energy office building in Belgium, built in 2001. The firm implemented an energy efficient heat pump to heat and cool their office building. This resulted in a reduction of the primary energy use by 29% and of the CO_2 emissions by 27% compared to the Belgian reference situation. The installation required a total investment cost of € 54.209 (€ 40,15/m²).

Conclusion

Reducing greenhouse gas (GHG) emissions is a major challenge, which Europe currently faces to achieve the overall aim to mitigate climate change. In this context, reducing the energy consumption of the European building stock is a priority. The greatest potential to reduce the energy consumption of the European building stock lies in measures for existing buildings, especially the oldest ones. Several actions with a high reduction potential have been identified. The implementation of HVAC and lighting control systems was an important action as it could result in a reduction of up to 20%. This potential can be unlocked with a cost that can be as low as € 3/m² for larger office buildings. When complemented with other quick-win actions such as implementing energy efficient lighting, system commissioning and, in the near future, installation of energy efficient heat pumps for heating and cooling, the GHG emissions reduction potential increases even more.

It is expected that the potential for reduced energy consumption through this action package is generally going to be similar across Europe. Nevertheless, the actions will lead to a differentiated total GHG emission reduction because the fraction of energy use per application (lighting, ventilation, space heating etc.) and the GHG emissions of the energy sources and electricity mixes differ significantly across Europe.

Macro Objective 2 – Resource efficient and circular material life cycles

Resource efficiency, as viewed from a life-cycle approach, is generally considered as an essential element on the road towards a circular economy. Resource efficiency therefore does not only refer to efficient use of resources, but encompasses minimising the environmental impact from the use of resources, bringing within its scope also waste prevention and recycling efforts, and more sustainable production and consumption patterns, to produce "*more from less*"[27].

The aim of the second macro objective for the building sector is to increase resource efficiency during the life cycle of buildings through:

- ✓ Optimised building design and engineering to support lean and circular flows;
- ✓ Extended long-term material utility and reduced environmental impacts, with a particular focus on full life cycle assessment (LCA);
- ✓ Building service life planning;
- ✓ Increasing recycling and reuse (design for deconstruction).

Efficient use of materials in the European construction sector

Despite differences in building culture across Europe, a number of "quick-win" actions have been identified in consultation with resource efficiency experts across European Member States. These actions offer a significant scope to realise the second macro objective and include:

- ✓ Low overall environmental impact of construction materials;
- ✓ Durable, low-maintenance materials for high risk elements;
- ✓ Prolonging building service-life with preventative maintenance strategies;
- ✓ Replacement of primary materials with secondary materials through increased reuse and recycling.

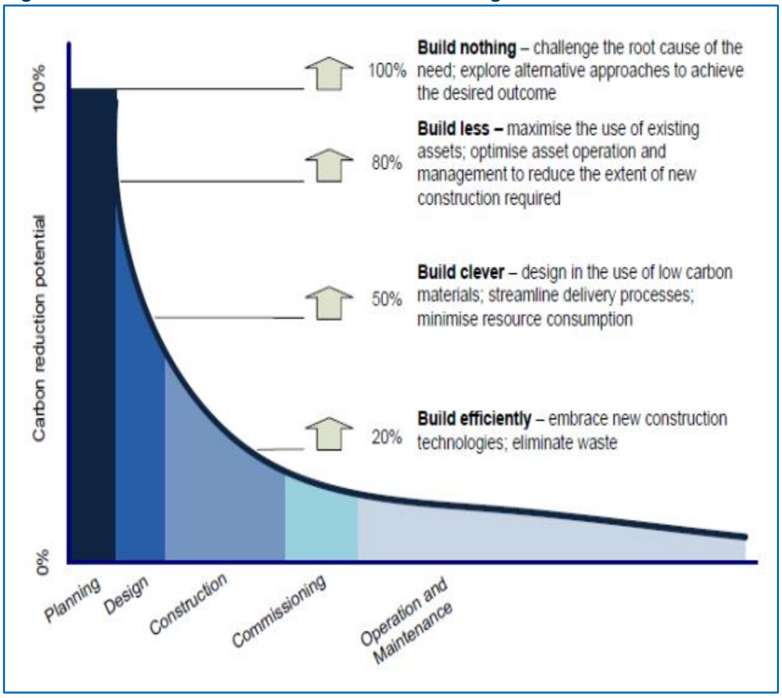
Consultation with experts in the field and literature reviews revealed a high potential for these actions to reduce embodied carbon emissions by approximately 25%. Various case studies analysed in the Netherlands, France, Italy and Denmark confirmed this potential. Literature[28] and expert judgements moreover indicate a significant potential to increase this number in a financially affordable way if LCA principles are applied from the design phase onwards. No case studies were found indicating the full environmental impact reduction achieved in a quantitative way for the selected cases, as LCA is not yet common practice in the design process.

Nevertheless, as each building is unique in terms of design, material composition and construction methods, there are very few, if any, straightforward solutions that can be applied across the board to increase the building performance. The main change that is needed in that respect is the adjustment of the thinking and action processes throughout all phases of the building life cycle to incorporate LCA.

27 https://www.eea.europa.eu/themes/waste/resource-efficiency/resource-efficiency
28 Allacker, K. (2010). Sustainable Building: The development of an evaluation method, PhD dissertation, September 2010, ISBN 978-94-6018-231-0

As indicated by the Infrastructure Carbon Review of the HM Treasury (see following figure), the potential to reduce embodied carbon emissions is increased with interventions taking place earlier in the building life cycle. Any action taken in that respect should therefore be put in the specific building context, especially the planning and design process and can be only specified on a case-by-case basis.[29]

Figure 3 Carbon Reduction Potential for Building Materials



Source: HM Treasury (2012). Infrastructure Carbon Review. https://www.gov.uk/government/publications/infrastructure/carbon-review.

Applying construction materials with low environmental impact

Selecting and applying construction materials with a low life cycle environmental impact has the potential to reduce material embodied carbon emissions with over 25%. This however requires a solid LCA in order to understand how the materials can be applied in the most appropriate way at building level. As such, it is important to not only consider the footprints of the individual materials, but to assess the footprint of the overall building solution.

Jane Anderson - The Alliance for Sustainable Building Products; United Kingdom

"Specific building case studies often point to a potential reduction of the carbon footprint of materials of about 25%, by both using more environmentally friendly materials and smarter designs."

Although materials with a lower environmental footprint are often seen by building owners as more expensive, studies have shown that considering them at the design phase with an LCA "lens" does not necessarily lead to additional costs. It was even shown that life cycle cost of low impact buildings often is lower than that of traditional buildings[30].

29 Interviews with Simon
30 Allacker, K. (2010). Sustainable Building: The development of an evaluation method, PhD dissertation, September 2010, ISBN 978-94-6018-231-0

Buildings consist of a wide range of construction products, such as wood, glass, steel, etc. Two examples to consider are concrete and aluminium[31]. They can both be used in ways, which significantly reduce their environmental impacts. The use of concrete with or without recycled content or the substitution between aluminium and wooden materials are tangible trade-offs in terms of environmental benefits.

Replacing aluminium for CO_2 emission reduction[32]

Research shows that aluminium-clad timber windows rather than aluminium framed double glazing curtain walling can bring 8% carbon savings for the total building in the case of an office building. With a rain screen cladding with terracotta facing rather than aluminium framed curtain walling, 8% carbon savings for the total building can be realised.

With an estimated savings potential of 25%[33] on a building's carbon footprint, a house with a total embodied carbon of 600 kg/m^2 could realise about 150 kg/m^2 of CO_2 savings. For an office building with a total embodied carbon of 1.104 kg/m^2, this would mean savings of 276 kg CO_2 per m^2.[34]

Lars Myhre - Norwegian Building Research Institute; Norway

"The development of low carbon concrete is an example. Low carbon/recycled concrete can reduce life cycle carbon emissions by up to 40% when compared with ordinary concrete."

Applying durable, low maintenance materials

The application of durable, low-maintenance materials in new and refurbished offices and residential buildings (including roofs, cladding, window frames, internal and external doors, kitchen unit frames, and floor finishes) offers scope to increase the building life span and reduce environmental impacts by avoiding manufacturing additional new building elements.

The use of more durable and higher quality materials leads to less maintenance activities and fewer replacements of construction products or building elements.

Using more durable and or higher quality materials does not imply higher planning or design costs, while they usually slightly increase the cost for construction and reduce the costs for operation and maintenance. These materials generally form only a minor part of the total construction cost, for which no significant effects are to be expected on the overall price tag for construction[35].

The use of more durable materials can extend the life span of specific elements significantly. It is assumed that a holistic approach to selecting materials that are more durable will extend the building life span by at least 5%[36]. For dwellings with a total embodied carbon of 600 kg/m^2, this life span extension would save 30 kg/m^2. For an office with a total embodied carbon of 1.104 kg/m^2, this would save around 55 kg/m^2. As such, the use of more durable materials can achieve these savings as well as those achieved through reuse, recycling and/or materials with a lower environmental impact.

31 http://ec.europa.eu/environment/eussd/pdf/Resource%20efficiency%20in%20the%20building%20sector.pdf
32 www.wrap.org.uk/sites/files/wrap/FINAL%20PRO095-009%20Embodied%20Carbon%20Annex.pdf
33 Jane Anderson
34 www.wrap.org.uk/sites/files/wrap/FINAL%20PRO095-009%20Embodied%20Carbon%20Annex.pdf
35 Jane Anderson
36 This is an expert judgement based on the expert consultation.

Prolonging building service life with preventive maintenance strategies

The action '*implementation of preventative maintenance strategies to maintain/prolong the service life of building materials*' refers to construction materials/elements that are at risk of degrading in terms of operational function. The two most common elements that are subject to such wear and tear are doors and windows.

Implementing a preventive maintenance strategy can potentially extend the life span of windows and doors by around 20% for a regular detached house, which can be translated to savings of 0,8 kg CO_2/m^2 for doors and 8,6 kg CO_2/m^2 for windows. Similarly, savings for an office building will be around 0,6 kg CO_2/m^2 for doors and 16 kg CO_2/m^2 for windows[37] [38].

Preventive maintenance strategies

Lars Myhre - Norwegian Building Research Institute; Norway: *"Currently, roofs need to be renewed every 30-40 years. Proper maintenance can avoid growing algae and a general check-up can expand the lifetime of a roof even further. A brick façade can last nearly forever. Wooden façades need maintenance every 6-10 years in order to last. These actions can increase the life span of houses from 20-30 years to nearly endless depending on the functional renovation needs."*

Nevertheless, it should be noted that increasing the technical physical life span of building elements does not necessarily mean an increase in the building service life. Buildings often reach the end of their service life, as they do not meet the users' need any longer.[39] Making building structures more flexible is a way to increase the life expectancy of buildings.

Flexible design to increase economic life span

In the city of Aalborg, Denmark, the city council and the defence ministry decided to refurbish old barracks into office space, residential buildings, workspaces and common areas. The activity began in 2012 and was planned to be completed in 2016. The new buildings would cover an area of around 92.700 m^2. The refurbishment plan included a very ambitious sustainability strategy with goals on carbon dioxide savings, water/heat/electricity savings, with a specific focus on resource savings. Moreover, the project has maintenance strategies in place for reducing the use of resources, mainly in terms of energy and water, both in the built and the common areas. A separate target was set for waste recycling at 65%. The architectural design of the new development allows for flexibility of the common areas, allowing them to shift almost freely from forest to grasslands or paved areas, in order to reduce maintenance. The building is part of a national project on green establishments that refers to transformations of old barracks into new sustainable urban developments.

Increasing recycling and reuse (design for deconstruction)

Designing buildings for easy separation of materials at refurbishment and at end-of-life allows disassembly for reuse or high quality recycling. As such, the potential for reuse and recycling of construction material is enhanced and on-site waste practically eliminated.
The implementation of design for disassembly would lead to a decrease in construction and demolition waste and to a reduction in the need for virgin materials by replacing primary with secondary materials.

37 Assuming embodied carbon in windows to be similar to that of a school building.
38 Calculations based on: www.wrap.org.uk/sites/files/wrap/FINAL%20PRO095-009%20Embodied%20Carbon%20Annex.pdf
39 Interview with Simon Sturgis, Sturgis Carbon Profilling, UK

Construction waste recycling

The city hall of Almelo in the Netherlands was completed in 2015 with sustainability as a key parameter in its design. The building includes 20.000 m² of floor area and 100 parking spaces, developed in line with the requirements for BREEAM Outstanding certification - the highest sustainability level for public buildings in the Netherlands. Through a series of interventions, the city hall of Almelo managed to recycle 95% of the waste generated on site during the construction. Moreover, during the selection of materials, special attention was given to their sustainability credentials.

The environmental benefits of these actions result from reuse and recycling in this case having lower environmental impacts than those from virgin alternatives. Although, the quantification of these benefits is not possible without knowing the exact bill of materials for a house being deconstructed, reuse and recycling is observed to have the potential to reduce on-site construction waste by up to 95% (see above example of the city hall in Almelo).

Conclusion

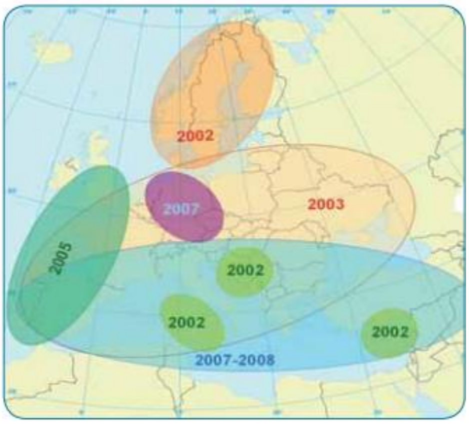
With an increasing demand to move towards a circular economy, the building sector is challenged to enhance the efficiency of its material use. However, data on the specific cost and benefits of enhancing efficient material usage in the building sector is limited and case specific. A general potential of reducing carbon-embodied emissions in construction materials by 25% has been observed. Moreover, the additional costs for selecting more environmentally friendly materials seem to be negligible for new buildings when these are considered from the design phase onwards.

Macro Objective 3 - Efficient use of water resources

With increasing droughts, reducing river flows, lowered lake and groundwater levels, and drying up of wetland, Europe is challenged to use water more efficiently. Buildings, accounting for the main consumption of water from supply systems[40], offer significant scope to tackle water scarcity through achieving more efficient water usage.

Hence, with the aim of the third macro objective for the building sector being "*make efficient use of water resources, particularly in areas of identified long-term or projected water stress*", actions have been linked to the identification and assessment of measures to enhance the efficient usage of water resources.

Main drought events in Europe since 2000



Source: http://ec.europa.eu/environment/pubs/pdf/factsheets/water_scarcity.pdf

Enhancing water efficiency in European buildings

Water consumption is naturally quite diverse across Europe. For example, as some countries are characterised by warmer climatic conditions or smaller household budgets[41], there are some observable differences in water consumption per capita in the EU.

> *Eurostat Data (2017) shows average water consumption to be highest in Southern Europe and lowest in Eastern Europe. Northwestern Europe is found in the middle of these two, explainable by its colder climatic conditions but higher household income.*

Despite these different water consumption patterns, in consultation with water efficiency experts in various European Member States, a number of "quick-win" actions have been identified offering a significant scope to improve water efficiency in buildings. These include:

- ✓ Installing water efficient equipment;
- ✓ Installing rainwater harvesting systems;
- ✓ Adapting user behaviour (incl. installing building leak detection systems and conducting water audits; Installing smart meters and providing guidance and training to operators and occupants)

Learning from existing cases in the United Kingdom, France, Italy, and Finland, and by consulting water efficiency experts[42] across Europe, these actions were found to have a total savings potential of at least 30% for both residential and office buildings.

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40 http://ec.europa.eu/environment/water/quantity/pdf/Water%20Performance%20of%20Buildings_Study2009.pdf
41 Waterprices also differ significantly across the EU ranging from 0,63 €/m³ (Malta) to 4,58 €/m³ (Denmark).
42 Expert interviews include: 1) Dr. Kemi Adeyeye – President Water Efficiency Network, UK; 2) Cath Hassel- ech2o consultants ltd, a UK environmental consultancy specialising in sustainable water and low carbon solutions for the built environment; 3) Prof. Armando Silva Afonso- President of the Board of ANQIP - Portuguese Association for Quality and Efficiency in Building Services; 4) Prof. Zuzana Vranayova- Director of the Institute Technical University of Košice, renowned expert on water efficiency in buildings.

For older buildings, this potential is found to even run up to 50%. Although this potential would not be feasible in all places, as local conditions differ, it provides an indication of what can generally be achieved. To illustrate this, varieties of case studies are presented below.

Water efficient appliances

Across all buildings, both old and new, there is scope to directly reduce water consumption through installation of water efficient equipment. In practice, this would involve the use of taps, showers, baths, urinals and siphon WCs that correspond to the upper quartile (top 25%) performance of the European Water Label or WELL Water Efficiency Label specifications. The examined case studies have shown that the savings potential of this action to be around 30% for all building types across Europe. With a payback period of around one to two years, installing water efficient equipment is proven to be a quick-win solution.

Reducing water consumption through office renovation

A former office building in Finland was transformed into a learning institution for the city of Helsinki. The building covers an area of about 4.300 m^2, and was completely renovated to comply with the Gold-level LEED certification. Water savings were realised through installing new water fixtures, such as waterless urinals and more taps that are efficient. Together these actions resulted in a 41% reduction in the annual water consumption.

Water efficient taps for all

In several Italian municipalities, water authorities and chain stores have collaborated to provide complete kits of water efficient tap adapters to household and public services (either for free or at a subsidised price). This led to an overall reduction in domestic water consumption of 30-50%. This would imply a reduction in the water bill of €59-98 for a household water consumption of 150 m^3/year and a tariff of €1,30/m^3.

Dr. Kemi Adeyeye – Water Efficiency network, United Kingdom

"The water savings potential in buildings can range between 5-50%. Depending on the building typology, generally speaking, buildings (e.g. semi-detached houses, apartments blocks, or office buildings) complying with the most recent standards are about 30% more water efficient (than average buildings of their typology and location)."

Prof. Zuzana Vranayová - Technical University of Košice, Slovakia

"Our research has shown that replacing high water-using devices with water efficient alternatives can reduce annual water consumption by more than 30%."

Prof. Armando Silva- Afonso – Expert water efficiency in buildings, Portugal

"For old buildings, changing the features has a return period of 1-2 years."

Usage of rainwater

Next to installing efficient equipment, rainwater-harvesting systems (RWHS) can be installed in buildings to substitute tap water, for example, using rainwater for garden watering, washing machine supply and toilet flushing. Notable tap water savings have been observed by installing RWHS. These savings are found to range significantly (from 5% up to 50%), being influenced to a large extent by two factors; 1) the size of the system and 2) the climatic conditions[43]. Generally, across Europe, the installation of such a system is considered a more long-term option, having a payback period of investment between 10 and 20 years.

50% savings with efficient equipment, meters, and RWHS

This case consists of five terraced houses built in December 2008 on the Inwood Road in Liss, in South-East United Kingdom. In all houses, a number of water saving devices were installed from the beginning, including dual flush toilets (two per house), low flow taps, aerated showerheads, and water butts. Additionally, three of the houses received water inlet meters to monitor and locate water usage. Two of the houses also received a rainwater harvesting system (RWHS) of 1.600 litres. Due to these interventions, from the outset the houses only consumed 55 l/p/d, about 50% less than the maximum allowed water usage to comply to the Code for Sustainable Homes (CfSH) level 3 according to which the houses were built.

Action	Cost in Euros[44]
Water savings devices	575,45
Water inlet meter	1.074,03
Rainwater harvesting system	4.029,06

Prof. Armando Silva Afonso – Expert water efficiency in buildings, Portugal:

"A rainwater harvesting system costs about € 10.000 for a small building (residential) and has a pay-back period of about 10-15 years. However, RWHs are especially interesting in hotter climates to save water for rainless periods."

Adapting user behaviour

Informing consumers of their water consumption, can stimulate them to become more efficient. A number of actions can be implemented to increase this awareness, for example, installing a building leak detection system or performing regular (every few years) water audits in residential building blocks or offices. These are simple-low cost actions that can produce major water savings. They allow the timely identification of water leakage and can prevent large losses of tap water of which the consumer might not be aware. Water audits in the UK for example generally only cost a few hundred euros for a medium sized office building[45].

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43 The potential of the RWHS (rain water harvesting systems) is highly dependent on 1) the level of precipitation and 2) the usage of rainwater. The latter depends on the demand of non-drinking water (e.g. watering gardens is more extensive in Spain during the summer months than in northern Member States)

44 Converted from pounds: 1 GBP =1.15065EUR (http://www.xe.com/currencyconverter/convert/?Amount=1&From=GBP&To=EUR [Accessed 10-01-2017]).

45 Cath Hassel, ech2o consultants ltd

Preventing large losses through water audits

A water audit was initiated in a school building in the Greater London area of the United Kingdom following a very high water bill due to a leak remaining unnoticed for months. Subsequently, the water auditors identified the leak and installed an Automatic Meter Reading (AMR) system, which provides a continuous signal to the water audit team. By monitoring this signal, the team assesses whether the water flow and consumption exceeds the normal consumption level. Within a month from installation, two water leaks were detected and repaired, preventing about €100.000 in excess water charges.

Smart water meters and real-time displays can be installed across all buildings informing consumers where and when water is used. Being informed, consumers can take action to use water more efficiently. Guidance/training for operators and occupants on the correct operation of water systems, maintenance requirements, and the implementation of preventative maintenance strategies will also improve consumers' water efficiency knowledge. Again, this increased awareness and knowledge will stimulate consumers to change their behaviour and take action, improving the efficiency of their water usage.

Studies assessing the impact of the installation of smart water meters on water consumption in the United Kingdom and France, found water savings of 5-10%[46] and 6-28%[47] respectively. Another trial with smart water meters in the United Kingdom resulted in an average water usage reduction of 3 to 4%[48].

The potential for water savings during renovation

This case consists of seven modern residential apartments (approx. 76 m^2 each) at 39 William IV Street in London, built in 1970 and renovated in 2016. The apartments are located on top of a 405 m^2 restaurant. The following actions were taken:

- ✓ Installing water efficient appliances, such as dual-flush WCs and low-flow taps;
- ✓ Fitting individual water meters in each apartment, so residents can proactively manage their water use;
- ✓ Providing Home User Guides for residents, to help them run the new space as efficiently as possible;
- ✓ Offering aftercare support to residents for at least 12 months, as well as carrying out on-site inspections and post occupancy interviews within three months after moving in.

The cumulative benefits of these actions are a 44% saving on water consumption with respect to the average water consumption of 150 l/person/day in the United Kingdom. With a water tariff of € 0.654 m^3 [49] this would imply an annual saving of £15 per person.

46 Environment Agency (2008), The costs & benefits of moving to full water metering Science Report – SC070016/SR1 (WP2).
47 M. Blinda (2014), More efficient water use in the Mediterranean, Water Efficiency Paper 14, November 2012. https://planbleu.org/sites/default/files/publications/cahier14_efficience_en.pdf [Accessed 07-12-2017].
48 House of Parliament, Parliamentary Office of Science & Technology (2014), Smart Metering of Energy and Water, POSTNOTE Number 471 July 2014.
49 https://www.thameswater.co.uk/my-account/billing-and-payment/our-charges/-/media/8BF91365689A4AC59CBA80C179AEFB32.ashx?bc=White&db=web&la=en&thn=1&ts=d8bc4555-b143-4a1d-ac4f-c31c83dbfa5b.pdf

Conclusion

With increasing droughts, reducing river flows, lowered lake and groundwater levels, and drying up of wetlands, Europe is being challenged to use water more efficiently. Quick-win actions in residential and office buildings - such as water efficient equipment, rainwater harvesting systems, leakage prevention, or smart meters and training - carry significant potential to reduce water consumption across Europe. These actions have the potential to make recent buildings 30% and older buildings 50% more efficient with a relatively small investment, and hence these actions are often economically attractive. Installing water efficient equipment generally has a payback period of only one to two years, offering a quick-win solution to reduce water consumption.

Macro Objective 4 - Healthy and comfortable spaces

We typically spend up to 90% of our time indoors, either at home, work or during other activities[50,51]. Air quality inside public and private buildings is an essential determinant of health and well-being according to this macro objective. Uncomfortable high temperatures, reduced ventilation and poor air quality cause distraction from work and can lead to symptoms such as headaches, difficulty to concentrate or think clearly[52]. In order to meet carbon reduction goals, future buildings will be increasingly well insulated and increasingly air-tight. The increased focus on air-tight building envelopes will require an increased attention for ventilation measures and VOC source control to ensure good indoor air quality, thus on the well-being of workers and building occupants for both new and refurbished buildings[53].

***Concentrations of VOCs** associated with building materials, such as carpets, finishes and cleaning products, may be at a level that is not only detectable by the olfactory sense, but also creates an irritant response, particularly when associated with high particulate concentrations, low humidity, or both. Pollutants are also emitted from office equipment, such as photocopiers and laser printers. Source control is the best way to minimise indoor air quality problems. This includes specifying low emission building materials, finishes and cleaning products to minimise 'outgassing'.*

Source: World Green Building Council, Wellbeing and Productivity in Offices. Research Note: Indoor Air Quality & Ventilation.

With the aim of the fourth macro objective for the building sector being "*to protect human health by minimising the potential for occupier and worker exposure to health risks resulting from exposure to chemical and biological hazards*", particularly with regards to improved indoor air quality, actions will focus on ventilation and source control.

Improving indoor air quality in Europe

Indoor air quality is influenced by a wide range of sources, including hazardous substances emitted from construction materials, furnishing and occupant behaviour, such as space heating and cooking. A wide range of pollutants and substances, such as radon, NO_2, CO, benzene, formaldehyde, TVOC, particles, CO_2, heavy metals and asbestos have been identified as hazardous to indoor air quality[54]. These chemical hazards as well as other hazards such as humidity and condensation can be associated with respiratory or allergenic health effects. This can lead to a broad range of health problems and may even be fatal[55] [56].

50 European Environment Agency, https://www.eea.europa.eu/signals/signals-2013/articles/indoor-air-quality [retrieved 29/05.2017]
51 JRC, http://indoor-air-quality.jrc.ec.europa.eu/, retrieved 26/5/2017
52 P. Wargocki, O. Seppanen (editors), J. Andersson, D. Clements-Croome, K. Fritzner & S. O. Hanssen (2006), Indoor Climate and Productivity in Offices – How to integrate productivity in life-cycle cost analysis of building services, Guidebook No. 6, by REHVA – Federation of European Heating and Air-conditioning Associations.
53 H. B. Awbi (2015), Indoor air quality in UK homes and its impact on health, School of built environment, University of Reading
54 JRC (2016), Identifying indicators for the life cycle environmental performance, quality and value of EU office and residential buildings
55 WHO Guidelines for indoor air quality, Selected pollutants, 2010
56 WHO Guidelines for indoor air quality, Selected pollutants, 2010, p. 1

In consultation with indoor air quality experts across European Member States, a number of "quick-win" actions have been identified offering significant scope to improve indoor air quality in buildings. Notably, these actions focus on reduction of VOCs and include:

- ✓ Installation of health-based ventilation rates;
- ✓ Application of low VOC emitting building materials;
- ✓ Building flush out and cleaning of ventilation systems prior to building occupation.

Learning from existing cases in Europe and the US - where data are transferable to European countries - and by consulting experts on the topic[57], improved indoor air quality in office buildings was found to increase productivity by up to 11% due to increased ventilation rates, dedicated delivery of fresh air to workstations, and reduced levels of pollutants[58]. This provides an indication of what can generally be achieved. In order to illustrate this, results from a variety of case studies are presented in the subsequent paragraphs.

Implementation of health-based ventilation rates

Ventilation rates can be improved by implementing natural ventilation measures and/or by installing and operating a mechanical ventilation system.

The benefits of improved air quality in residential buildings are not measured but assumed[59]. Improved air quality in residential buildings mainly provides health benefits due to a reduced risk of asthma and allergies, as well as improving sleep and performance. Natural ventilation based on improved window design might be the preferred option in smaller residential buildings.

In office buildings, financial benefits related to improved air quality typically include: 1) reduced medical care costs, 2) working days gained due to reduced sick leave, 3) better performance at work including increased productivity, 4) lower staff turnover and 5) lower cost of building maintenance[60]. Clearly, the majority of these financial benefits are based on health benefits.

Kasper Lynge Jensen, Director of Development at Aarhus School of Engineering, Denmark

"Employers have to understand the impact of indoor air quality on worker performance and, thus, the benefits related to improved productivity."

According to the World Green Building Council, from a performance and health perspective, the suggested ventilation rate for office buildings is between 20 and 30 l/s. Additional benefits progressively tail off above 30 l/s. Using the number of days of sick leave as an indicator for good indoor air quality, case studies showed that short term sick leave was 35% less in offices ventilated by an outdoor air supply rate of 24 l/s compared to buildings with ventilation rates of 12 l/s[61].

57 Expert interviews included: 1) Pawel Wargocki, Associate Professor at the Technical University of Denmark; 2) Kasper Lynge Jensen, Director of Development at the Aarhus School of Engineering; 3) Ruben Stuijk, Architect and building professional, Belgium

58 World Green Building Council, Health, Wellbeing & Productivity in Offices. The next chapter for green building

59 Interview with Kasper Lynge Jensen and Pawel Wargocki

60 P. Wargocki, O. Seppanen (editors), J. Andersson, D. Clements-Croome, K. Fritzner & S. O. Hanssen (2006), Indoor Climate and Productivity in Offices – How to integrate productivity in life-cycle cost analysis of building services, Guidebook No. 6, by REHVA – Federation of European Heating and Air-conditioning Associations, p. 13.

61 World Green Building Council, *Health, Wellbeing & Productivity in Offices. The next chapter for green building*
http://www.jll.com/Research/Health_Wellbeing_Productivity.pdf?1a56c1ad-7be7-4d6d-8f32-74bb6e72fa3f
P. Wargocki, O. Seppanen (editors), J. Andersson, D. Clements-Croome, K. Fritzner & S. O. Hanssen (2006), *Indoor Climate and Productivity in Offices – How to integrate productivity in life-cycle cost analysis of building services,* Guidebook No. 6, by REHVA – Federation of European Heating and Air-conditioning Associations

Productivity benefits from improved indoor air quality in office buildings

A study simulating an office building compared the investment cost for improving indoor air quality with resulting revenues from increased office productivity due to improved worker performance. "The results showed that the annual benefits from improved productivity are higher than the annual costs of energy and maintenance in running a heating, ventilation and air-conditioning (HVAC) system. For an office building situated in a moderate climate with an HVAC system with constant air volume, the installation costs of the HVAC system were estimated to be around € 118/m² [62]and annual maintenance and energy costs[63] of around € 29/m². Based on these costs, the overall annual benefit due to improved air quality was found to be up to 115 times higher than the increase in annual energy and maintenance costs." [64]

Kasper Lynge Jensen, Director of Development at Aarhus School of Engineering, Denmark

"The benefits of improved air quality in residential buildings are assumed but difficult to prove. The focus of interventions should be on stimulating behavioural change. Smart systems can improve air quality if occupants are guided to use ithem appropriately. A sensor informing occupants of poor indoor air quality can stimulate natural ventilation while costing less than € 100."

Especially in relation to office buildings, indoor air quality can be improved by installing a mechanical ventilation system. For an existing office building, figures show that the installation of a central ventilation system on the roof or attic or a decentralised system attached to the window in each room or façade cost in the range of € 35 to 200/m² floor area[65]. The exact cost of this action depends on the complexity of the installation and the building. This means that depending on the size of the rooms and the design of the ventilation system, the price might be higher.

These measures, however, increase energy consumption, amounting to € 30-40/m² floor per year. In general, the lifetime operating costs for energy and maintenance of a building are five to six times higher than its construction phase costs. However, data from simulated case studies and expert statements show that annual benefits from improved health and productivity are higher than the additional cost for energy and maintenance. Hence, these additional costs are easily offset by the value created by workers in the building.

Ruben Stuiik, Architect; Belgium

"In Belgium, the investment costs of installing a simple system with mechanical extraction and natural intake in the renovation phase of a residential building of 280 m² costs around €3.500, while in a new build residential building of 220m², a system with mechanical intake and extraction with heat recovery costs around €8.500. Depending on the design of the ventilation system, the unit price for a system with mechanical intake and extraction with heat recovery in a new build office building (670m²) costs around €29.500, whereas the installation of such a system in an existing office building of 733 m² costs around €25.000."

62 Conversion rate: $1=€0.89. $133.7=€118

63 Given that the indoor air quality should reach a level where 10% of the people entering the building would be dissatisfied.

64 Wargocki, P. and Djukanovic, R. (2005), Simulations of the potential revenue from investments in improved indoor air quality in an office building, ASHARE Transactions, vol. 111 (pt. 2), pp. 699-711, p.

65 Calculated per m² based on a unit price for a ventilation system procured and installed in Belgium, e.g €25,000 : 733m² = €35 pr. m²

Application of low emitting building materials

In addition to ventilation measures, indoor air quality can be improved by controlling the emission of harmful pollutants, including VOCs, by using low emitting building materials.

Low-emitting building materials and perceived air quality in an office building

Wargocki, P. et al. (2007) investigated the relationship between the selection of low-polluting building materials and the perceived air quality in an office building. They found that the improvement of the air quality was greater than the improvement obtained by increasing the ventilation rate within a range that was realistic for indoor settings. The study showed that reducing pollution sources by selecting lower-polluting building materials improves the perceived indoor air quality. This offers the possibility to reduce the ventilation rate and hence reduce the energy use without negative consequences for the indoor air quality[66].

The use of low-emitting building materials for the construction of an office building without additional operation or maintenance costs has been found to bring an annual benefit of around € 27/m² due to increased worker productivity. The dissatisfaction rate with the indoor air quality amongst the occupants of the building can be reduced by 10% without increasing the outdoor air supply rate[67].

The application of VOC absorbing construction materials is a forward-looking action, as these materials are not yet considered to be a technology applicable for widespread use because many of these products currently are at the research and development stage. Their application is not common practice in Europe and no data on costs and benefits could be identified.

Building flush out and cleaning of ventilation systems prior to building occupation

Pre-occupancy building flush out is a process in which the building is ventilated after construction at a certain rate for a period, lasting from a few days to several weeks. This process forces air through a building prior to occupancy to remove harmful pollutants such as VOCs emitted from building materials and newly installed components, including paints, finishes and furnishings. After the process, ventilation filters need to be renewed. The process aims to improve indoor air quality by limiting occupants' exposure to the most intense period of contamination[68].

Application of low VOC emitting construction materials, building flush out and natural ventilation

A case study conducted in a lab environment in 2003 simulated the behaviour of a newly constructed residential house. The study found that the application of low VOC emitting materials combined with a three month pre-occupancy building flush out and regular natural ventilation with an average air exchange rate[69] of 0,36 h^{-1} (low rate) and 1,6 h^{-1} (high rate) decreased the total VOC concentration in the house to 43 µg/m³ to non-detectable[70]. This is far below the average concentrations of VOCs measured in dwellings in Europe (149 - 470 µg/m³)[71].

66 Wargocki, P. et al. (2007), Effect of using low-polluting building materials and increasing ventilation on perceived indoor air quality
67 Wargocki, P & et al., Simulations of the potential revenue from investment in improved indoor air quality in an office building (2005), p. 5
68 Minnesota Sustainable Housing Initiative: www.mnshi.umn.edu/kb/scale/flushout.html
69 The volume of air filling a room is changed between 0,36 and 1,6 times per hour.
70 H. Guo, F. Murray, and S. C. Lee (2003), The development of low volatile organic compound emission house – a case study, in Building and Environment 38.
71 Karakitsios, S & et al., Integrated exposure for risk assessment in indoor environments based on a review of concentration data on airborne chemical pollutants in domestic environments in Europe (2015) in Indoor and Built Environment, Volume: 24 issue: 8, page(s): 1110-1146

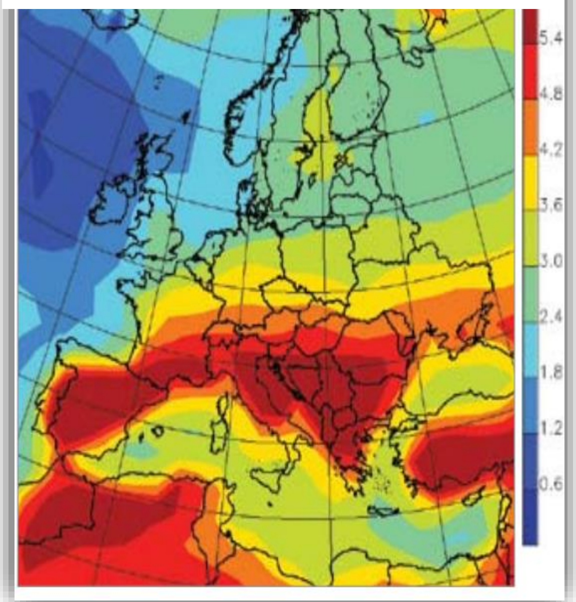
Conclusion

Measures related to improved indoor air quality in both office and residential buildings are expected to become even more important in the future due to the impacts of climate change. The increased focus on air-tight building envelopes will require an increased focus on ventilation measures and source control to achieve good indoor air quality, and therefore ensure the well-being of building occupants. Notably, taking actions to improve ventilation rates and control sources of VOC in office environments, involves investment and operation costs that are quickly offset by the financial benefits of improved employee health, performance and productivity, with reductions in sick leave being potentially as high as 35%. For residential buildings, natural ventilation requires low investment and operational costs as it requires minor adjustments and mainly behavioural change, with the main benefit relating to the improvement in residents' health. Finally, pre-occupancy building flush out can contribute to the above at a relatively low cost.

Macro Objective 5 – Adaptation and resilience to climate change

Looking at the second half of this century, a large part of the European building stock is not well equipped to cope with a changing climate. Old buildings lack an efficient thermal envelop and new air-tight buildings often lack sufficient ventilation and, hence, both are seen as vulnerable parts of the building stock. Specifically, up to 25% of the current building stock of non-residential buildings (including office buildings) will need extensive retrofitting to effectively manage the increasing temperatures or otherwise face unsustainable increases in energy bills. Further, as heatwaves are associated with increases in mortality rates and other negative health impacts, and uncomfortably warm office temperatures can greatly affect productivity, failing to adapt building stock can result in an increased severity of these impacts as the climate change phenomenon unravels.

Simulated average summertime temperature change between 1961-1999 to 2070-2099



Juan Lafuente –Author of RICS, Climatic Risk Toolkit, 2015

"If climate change impact is not addressed, the economic life-time of a building can be reduced in view of increasing energy bills."

Improving thermal comfort in the European building stock

Overheating will be an issue for both older buildings with high building envelope U-values and buildings that are more recent which are very air-tight and poorly ventilated, even if located in the "mildly" affected countries such as the UK[72].

Lars Myhre – Technical Director, Norwegian Home Builders' Association, Norway

"Generally, new buildings, which typically are better insulated and have improved air-tightness, might perform worse regarding overheating compared to already existing buildings, especially if adequate ventilation is not foreseen."

With the time horizon for this macro objective set in the long term and, regardless of the location and existing condition of a building, a number of "quick-win" actions can make a substantial difference in improving thermal comfort.

72 www.extreme-weather-impacts.net/toolkit/detached/index.html#

These include:

- ✓ Minimising heat gains;
- ✓ Implementing energy efficient cooling options (including increased ventilation rates and using energy efficient heat pumps for HVAC73 in the long term).

Additionally, the effectiveness of both actions is maximised when providing guidance and training to achieve behavioural change.

Prof. Bienert – Real estate expert, Institut für Immobilienwirtschaft, Germany

"Overheating is not yet perceived as an important issue influencing real estate values in Germany, although it is an issue for some specific building types. This is an important factor in Spain where the costs of air conditioning can be significant. However, with rising temperatures, overheating might become an important issue in the future in Germany as well".

Quantitative reporting on the costs and benefits of mitigating climate change is scarce in the literature. This is partly because the time-horizon of these actions render only a simulated *ex-ante* assessment possible. Another reason is the fact that quantitatively assessing climate-proofing actions for buildings has been the point of attention for a limited part of the building industry (also geographically[74]) and performed mainly for high-end private offices as part of a CSR policy and by some public organisations. Costs and benefits have been retrieved from specific case studies from Germany, the United Kingdom and Belgium. Consultation has been conducted to expand and validate these findings with building climate change resilience experts[75] with experience from various EU countries[76].

Combinations of these actions provide the potential to eliminate 30 to 100% of the overheating duration in a building (depending on the specific building). Consequently, this can result in a minimum saving of 30% in cooling costs. Arguably, the largest benefit for offices is the 1 to 3% productivity increase. Depending on the productivity level and overheating exposure, a payback period of between one and six years can be expected. These figures are illustrated in the following sections.

Minimising solar heat gains

A first measure to prevent overheating in a building should be the avoidance of solar gains. Improving shading and installing improved glazing to reduce heat gains are two of the most important actions to minimise the impact of increasing temperatures. This is especially relevant for non-air conditioned buildings. For offices, applying solar rejection window films, brise soleil, installing external fixed shading and blinds can increase comfort hours by more than 40%, as illustrated by the German office case below. In less affected climates (e.g. England, North France, Scandinavia) it may even eliminate the impact of rising temperatures altogether. For Southern Europe, shading alone cannot be a viable solution throughout the year, although it can reduce the duration and intensity of the cooling needs.

73 Heating, ventilation and air conditioning
74 The UK seems to have the most active reporting on the subject.
75 Expert interviews included: 1) Lars Myhre – Technical Director, Norwegian Home Builders' Association,; 2) Juan Lafuente – Expert, building climate change resillience expert; Sturgis Carbon Profilling, UK, Author of the RICS, Climatic Risk Toolkit, 2015 http://www.globalabc.org/uploads/media/default/0001/01/f168fb64573a74da207efdfbc4076d2781d2fac5.pdf; 3) Prof. Bienert – Real estate expert, Institut für Immobilienwirtschaft, Germany; 4) Pawel Wargocki - Associate Professor Ventilation and Climatic systems, Technical University of Denmark; 5) Kasper Lynge Jensen – Air Quality and ventilation expert, Director of Development at Aarhus School of Engineering; Denmark
76 Denmark, France, Germany, Greece, Ireland, Norway, Poland, Spain, Sweden and the UK

The relevant costs depend on the severity of the problem each building is facing and can range from € 10 to 50/m^2 depending on the selected solution[77].
It should be noted that it is probable that initial simple adaptation measures can suffice for a number of years before higher impact solutions will need to be applied.

Residential buildings, especially in Northern Europe, can also apply very simple solutions such as installing external blinds, thick curtains and painting south facing walls in lighter colours. Such measures come at very limited cost and, in combination with improved natural ventilation (see subsequent section); can suffice for the majority of residential buildings in Northern Europe. Behavioural good practices applied in Southern Europe, like night-time ventilation, can be copied to improve building performance in the North.

Juan Lafuente –Author of RICS, Climatic Risk Toolkit, 2015

"In the United Kingdom, it is possible to reduce the overheating exposure of buildings by half in residential sector typologies (older ones – Victorian styles etc.) with simple adaptation measures."

Climate-proofing office buildings with gradual application of shading solutions

A three building cluster owned by Cornwall Council in the UK has been studied in order to devise a climate adaptation strategy. This consisted of a gradual application of improved shading and ventilation options applicable as temperatures rise in view of the 2080 time horizon. Solar rejection films came at lower costs (approx. € 15 /m^2) and were considered to suffice for a 10-year mitigation period before more drastic measures would be needed. Installing brise soleil secured adaptation for 40 years but came with larger costs (up to € 50/m^2) with technical solutions depending on the specifics of the building.

Balancing solar shading with lighting costs

The German Federal Office for Building and Regional Planning, Berlin is located in a new-build office that suffers severely from overheating. Various adaptive shading solutions have been simulated comparing the investment costs required and the additional needs for lighting due to the shading with the reduced cooling costs. The assessed solutions managed a temperature decrease of 3 to 6 ^{o}C and decreased discomfort hours by up to 50%. This study proved that while the shading options can perform similarly in terms of reducing temperature, the impact on additional lighting costs ranged significantly € 0,78 – 3,77/m² per year. This shows that investment costs (€ 10,92 – 14,71/m²) are not the only variable to consider.

Adapting user tolerance by steadily increasing maximum allowed office temperature over the year, can have a critical impact on reducing lighting and cooling costs as seen in the German office case above[78].

77 Or combination of solutions to improve shading and window glazing.
78 Ascione, F., et al), Summer overheating in a new multi-storey building in Berlin: numerical study for improving the indoor microclimate, Energy Procedia 75 (2015) 1305 – 1314

Energy efficient cooling options

As well as reducing heat gains, buildings that are more exposed to the impacts of climate change will need to implement an effective cooling strategy. There is a dual strategy in doing so, applicable to both residential and office buildings.

Firstly, in Southern Europe, air conditioning systems are already common practice, as ventilation without an air conditioning system would not suffice. The focus here should be on improving the air-tightness of the buildings to preserve internal temperatures. Efficient heat pumps can be a viable solution in the near future replacing existing A/C units and prompting a substantial energy efficiency improvement for HVAC of up to 30%. This currently come at a cost of approximately € 40/m² for larger office areas, but is expected to become significantly cheaper as the technology matures[79].

Kasper Lynge Jensen – Director of Development at Aarhus School of Engineering, Air Quality and ventilation expert; Denmark
"For office buildings, mechanical ventilation is the way to go. This is common practice for new buildings. A simple ventilation system bringing the temperature from 28 to 22 °C brings 1-3% gains by increasing productivity and improving health as estimated for Scandinavian countries. For Southern countries, ventilation needs to be combined with a cooling system."

Secondly, for buildings in Central and Northern Europe, increasing ventilation rates is the way forward[80]. A primary action is to prompt user behaviour change, adopting night ventilation to purge excessive heat and adopting "window opening rules". This comes at no or minor costs for residential buildings through adjustment of window frames for security purposes. Modelling the impact in detached houses and top floor apartments in the UK revealed a reduction in overheating hours of 30 to 50%. For office buildings, although an attractive alternative, night ventilation might not be an applicable option due to security concerns. Thus, the installation of a central mechanical ventilation system is suggested. Procuring such a system for a new building can cost as little as € 35/m² while the cost of installing it in an existing building can be significant, up to € 200/m², depending on the building specifics, in which case a decentralised system might be preferred. While operation and maintenance costs also need to be applied to such systems (roughly € 20/m² /year) [81], the main benefits relate to the increased productivity that can be as high as 3%.

Combining heat gain reduction with efficient ventilation
The CREW project modelled the impact of climate change in different common building typologies in the UK with the time horizon set to 2080. An increase in overheating hours was estimated to be more than 500 degree-hours for detached houses from the 60's and to more than 700 degree-hours for new low specification top floor apartments. Mitigation of impacts was achieved with a variety of simple measures such as i) adapting user behaviour (i.e. night ventilation, window opening rules, light coloured walls) and ii) providing improved solar shading (i.e. external shutters, external fixed shading, low-e triple glazing windows, internal blinds). These led to a modelled decrease in overheating hours by 30 to 50% for detached houses at costs ranging between € 2.500 and 15.000 per housing unit. For top-floor apartments, the overheating time reduction was as high as 35%. This came at minor costs mainly linked to improved window security.

79 See case SD Worx office
80 Interview Juan Lafuente
81 Cost assessments from interview with Kasper Lynge Jensen. Procurement prices fo not differ significantly across the EU, installatio costs refer to a Danish context.

Conclusion

Climate change is a problem with a long time horizon. Looking at the second half of this century, a large part of the European building stock is not well equipped to cope with a changing climate. Old buildings lack an efficient thermal envelope and new air-tight buildings often lack sufficient ventilation, and hence both are seen as vulnerable parts of the building stock. A combination of adapting user behaviour, improving ventilation and minor retrofits aiming to improve shading of existing residential buildings and offices is needed. In residential buildings, simple actions costing between nothing (behavioural change) and the cost of a minor retrofit action[82] should suffice to counter between 30 and 100% of the expected overheating impact, resulting in an improvement of thermal comfort and residents' health, and/or cost savings for avoided active cooling. For office buildings, improved solar shading (costing approx. € 10 to 50/m^2) would suffice for the less impacted areas and/or for the first years of mitigation. This can be complemented with a central mechanical ventilation system for slightly more impacted cases with systems that can cost between € 40/m^2 for new buildings and € 200/m^2 for complex fitting in existing structures. Nevertheless, as already common practice in Southern Europe, combining this with a cooling system is unavoidable for the most impacted buildings. Despite the high costs, the significant expected productivity gains (1-3%) brings the payback period to between 1 and 6 years.

82 Retrofitting window frames estimated at 15.000 € for an average 2006 single-family detacehd house in the UK.

Macro Objective 6 – Optimised life cycle cost and value

The life cycle costs of buildings are often higher than necessary because too often solutions are selected based solely on investment costs. In order to maximise the life-cycle value of buildings, it is important to look further than the investment cost to ensure a cost effective building operation as well as a good future market value. Durable materials, which require a higher investment cost, for example, may still be preferred from a life cycle cost perspective because they require lower operational costs - due to less frequent replacements that are needed and/or due to lower maintenance costs.

Therefore, in the context of this macro objective for the building sector "*optimise life cycle cost and value*", four actions are proposed to reduce the life cycle costs representing the "low-hanging fruits" that can be easily and effectively implemented for the majority of the building stock. To discuss the costs and benefits related to this macro objective, the additional investment cost and the total life cycle cost savings are respectively seen as indicators. As total life-cycle costs are not commonly calculated for a building, improvements in that respect are more often replaced by more specific cost savings such as reduced energy bills or reduced maintenance costs.

Reducing life cycle costs for European buildings

The four actions identified to improve life cycle cost in buildings include:

- ✓ Use of durable, low-maintenance materials (for high risk elements);
- ✓ Installation of and user guidance for the operation of HVAC control systems;
- ✓ User guidance/training and implementing preventative maintenance strategies to prolong the service life of building materials;
- ✓ Designing services and service routes for ease of access for maintenance and refurbishment.

The analysis of these actions in existing cases in Belgium, Austria, the United Kingdom and the US in combination with additional information from interviewing experts has shown a potential reduction in life cycle costs of up to 20% in existing buildings, and 5% in new-builds.

Durable, low-maintenance materials

Using durable low-maintenance materials has been identified as an important action in reducing the life cycle cost of a building, as this requires less frequent replacements and/or maintenance. This leads to a decrease in the quantity and cost of the materials needed during the life span of the building and in less labour costs for maintenance/replacement activities. Using durable, low-maintenance materials can lead to life cycle cost savings of up to 16% (see next case study). The direct benefit of this action is not only a lower life cycle cost, but also a reduction in GHG emissions (macro objective 1) and the achievement of a better life cycle environmental impact (macro objective 2).

The potential to reduce life cycle costs by using durable, low-maintenance materials

In Zelzate, Belgium, a residential building, originally built in 1960, will be refurbished in 2017 into a future oriented residential community. The total life cycle cost was taken into account during the design process. A minimum reduction of 2% of the life cycle cost was obtained for the outer walls, while for the ground floor, a reduction of 16% was estimated compared to current common practice alternatives. The additional investment cost to achieve these life cycle savings compared to common practice varied between € 13,24/m² wall for the outer wall and € 65,46/m² floor for the ground floor. While for the majority of the elements the maintenance costs were reduced, the investment and replacement costs increased. This led nevertheless to a reduction in life cycle cost.

Installation of and user guidance for control systems for heating, ventilation, air conditioning and lighting

Advanced control systems for heating, ventilation and air conditioning (HVAC) and lighting are identified as another important opportunity to reduce building life cycle costs. It is however important to note that this should be combined with appropriate training and guidance to ensure full effectiveness. The case studies confirmed that such control systems can lead to a significant reduction in operational energy costs. In old office buildings, for example, the energy bill can be reduced by up to 20%, as can be seen the section on macro objective 1. In addition, a further reduction in energy costs may be achieved by system commissioning.

The investment cost for the installation of control systems in office buildings found in the cases studied[83] range between € 3 to 270/m². This rather wide range can be explained by the big variety of control systems, going from a small management system with sensors to advanced building management systems. To illustrate the potential of the life cycle savings due to the installation of HVAC and lighting controls, refer to the Legacy Civic Towers in San José, California, as discussed in macro objective 1.

User guidance/training and implementing preventative maintenance strategies to prolong the service life of building materials

Guidance and training aimed at prolonging the service life of a building through implementing preventive maintenance is assumed to result in lower maintenance and replacement needs, which compensate the additional investment cost required. A lower life cycle cost is hence expected, but no quantitative data were found to support this assumption.

83 See Annex II

It is also assumed that a user guide will lower the operational energy use, as occupants will have access to information on how to better use their energy consuming systems and appliances, resulting in energy savings.
A user guide is assumed to have a negligible cost. If provided, it is part of a post-intervention file, which requires an investment cost of about € 500 for a dwelling (i.e. € 400 – 600 depending on the size of the building and type of intervention).

The potential to reduce life cycle cost through guidance/training

The sustainable neighbourhood in Waregem, Belgium, is a pioneering project by Wienerberger consisting of seven attached zero-energy houses built in 2016. The neighbourhood is innovative from its holistic sustainability approach, i.e. considering social, ecological and economic aspects. The project has a BREEAM Excellent rating. Linked to the BREEAM requirements, a home user guide was provided as part of the post-intervention file. This post-intervention file had a total cost of € 400-600. A user guide ensures that the occupants use the building and its installations in the most efficient way.

[De Duurzame Wijk, Zultseweg 7, 8790 Waregem, Belgium]

Design of services and service routes for ease of access for maintenance and refurbishment

Improving the building design to facilitate maintenance activities and providing relevant information to constructors and building occupants are expected to lead to important financial benefits, as a cost reduction is expected due to the ease of access (and hence increase in time efficiency and less deconstruction needed) and lower renovation costs to adapt the building when its use changes. Both actions will demand additional investment costs as it is expected that the change in design approach will require additional time (and hence an additional cost) for designers to become accustomed to this. However, this is seen as a temporary situation, because once the designer is used to this new design approach, the design process will be equally or even more efficient and will not require any additional cost. Despite the potential of this action to reduce life cycle costs, there are only a few case studies available, none of which contain cost/benefit calculations.

The potential of design of services and service routes

Building 2226 is an office building in Vorarlberg (Austria), designed by the architectural office Baumschlager & Eberle and was finished in 2013. Building 2226 is an ultra-low energy building, which does not have a heating, cooling or mechanical ventilation system. In the building, a vertical shaft of approximately 1 m² contains the few ducts and cables. Openable parts are provided in the floor to allow for easy access to cables in the raised floor construction. Maintenance and replacement of the services are easier with these interventions. This will result in reduced labour costs and reduced material costs.

Conclusion

Currently the design process most often focuses on minimising the investment cost instead of the building life cycle cost. There is significant potential to reduce the life cycle cost of buildings, which ensures affordability over its life span and a good future market value. Building measures such as the use of low-maintenance materials and control systems have a high potential to reduce the life cycle cost. Energy bills can be reduced by up to 20% for existing buildings and by up to 5% for new-builds through control systems. In addition, user guidance and training and design strategies to simplify maintenance and replacements during the building life span have a high potential to reduce costs, although these savings were not quantified in the cases analysed. Overall, the combination of building measures and user guidance can easily lead to a reduced life cycle cost of a building.

Study on cost and benefits of working towards environmental macro objectives in the building sector

Annex Report

Client: European Commission, DG Environment

Rotterdam, 24 October 2017

Study on cost and benefits of working towards environmental macro objectives in the building sector

Annex

Client: European Commission, DG Environment

Ioannis Giannelos

Rotterdam, 20 June 2017

ECORYS

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Annex I Expert consultation

The experts consultation approach followed in the course of this study is performed for three main purposes. First for formulating the Action Packages for each of the macro-objectives, second for validating them and third for assessing the costs and benefits linked to their implementation.

For the three purposes, different subsets of experts where consulted. Table 1 underneath presents the experts that participated in the workshops to formulate the Action Packages

Table 1 Macro objective workshop schedule and expert panellists

Macro objective workshop	Expert panellists
Macro objective 1: greenhouse gas emissions from building life cycle energy use Monday 31st October 2016 (1330-1630 GMT)	Andy Lewry (BRE) John Henderson (BRE) Owen Abbe (BRE) Karen Allacker (KU Leuven) Ioannis Bakas (CRI)
Macro objective 2: Resource efficiency Monday 31st October 2016 (0930-1230 GMT)	Gilli Hobbs (BRE) Flavie Lowres (BRE) Owen Abbe (BRE) Karen Allacker (KU Leuven) Ioannis Bakas (CRI)
Macro objective 3: Water efficiency Tuesday 1st November 2016 (1330-1630 GMT)	Steve Brown (Water Energy Nexus) John Griggs (JPJN Partners Ltd) Cath Hassell (ech2o)
Macro objective 4: Indoor air quality Wednesday 2nd November 2016 (0930-1230 GMT)	Andy Dengel (BRE) Vina Kukadia (BRE) Chetas Rana (BRE)
Macro objective 5: Thermal comfort and overheating Wednesday 2nd November 2016 (1330-1630 GMT)	David Butler (BRE) Alan Abela (BRE) William Wright (BRE)
Macro objective 6: Life cycle costs Tuesday 1st November 2016 (0930-1230 GMT)	Mike Clift (BRE) Kathryn Bourke (Whole Life Ltd) Anthony Waterman (ADW Developments Ltd) Karen Allacker (KU Leuven)

Table 2 presents the international experts consulted to validate the applicability of the Action Packages across the EU.

Table 2 Experts asked to validate the draft action packages

Name	Organisation	Role	Location	Replied
Andromaque Simon	Green Imagineering	Architect & BREEAM Assessor	France	Yes
Hans van de Sanden	Sweco Consulting sp. z.o.o.	Architect & BREEAM Assessor	Poland	Yes
Timo Rintala	Green Building Partners Oy	Sustainability Expert & BREEAM Assessor	Finland	Yes
Oscar Martinez Lamigueiro	Instituto Technologico de Galicia (ITG)	Architect & Director BREEAM ES	Spain	Yes
Kjersti Folvik	Norwegian Green Building Council	Engineer & Chief Executive Officer NGBC	Norway	Yes
Martin Mooij	Dutch Green Building Council	Architect & Head of Certification and Management	Netherlands	Yes
Pantelis Levantis	Ecoveritas	Managing Director, BREEAM Assessor & President of Sustainable Building Council of Greece	Greece	Yes
James Drinkwater Audrey Nugent	World Green Building Council	Regional Director, Europe Network Senior Policy Advisor, Europe Network	Europe	Yes
Sasa Marenjak	Croatia Green Building Council	Board Member & DGNB Assessor	Croatia	Yes
Pascal Eveillard	Saint-Gobain	Strategy, Marketing, Public Affairs & Sustainable Development	France	Yes

Finally, the experts consulted to assess the costs and benefits of the proposed actions are presented in the subsequent chapters in which they are presented.

Annex II Sources tables

MO 1 – Energy efficiency

Table 3 Cost and benfits sources for MO 1 - Energy efficiency

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
Building case studies											
Case studies with quantitative cost/benefit data											
Low Energy Renovation Spiere	I	1C	Belgium	168m^2	1900 (2014)	20% energy cost reduction for space heating (= 14,5 % reduction energy bill)	20% energy reduction for space heating		Increased comfort	€26.790 (= 159,5€/m²) for airtightness and thermographic	
House in Neerijse	I	1A	Belgium	180m^2	1950 (2016)	90% energy cost reduction for lighting (= 2,1% reduction energy bill)	90% energy reduction for lighting			€216 (=3,32€/m²) for LED lighting	
Sustainable Neighbourhood Waregem	I/II	1A/1C/1E	Belgium	190m²	2016	90% energy cost reduction for lighting (= 2,1% reduction energy bill) 12,5% energy cost reduction for space heating (=9,1% reduction total energy bill) by air tightness	90% energy reduction for lighting 25% reduction of Net energy demand of space heating (air tightness + windows) Estimated		Increased comfort	Assumed around 3,3 €/m² for LED light bulbs €655 (=3,4€:m²) for the airtightness of one housing unit (7 in total) in comparison	1% of investment cost as maintenance (=168 €/year)

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
						12,5% energy cost reduction for space heating (=9,1% reduction total energy bill) by window improvement	potential energy reduction of 15-20% by monitoring			for improvemen t +- 1vol/h €4.541 (23,4 €/m²) extra investment for windows 16.800 euro (86,6€/m²) for Heat pump/housi ng unit in comparison with E60 norm blowerdoor: 485-629 €/house	
Building 2226	III	1B/1D	Austria	2,700m²	2014	No data available on the benefits, but can be estimated based on installed power and hours of use per year	No data available on the benefits, but can be estimated based on installed power and hours of use per year		Increas ed indoor air quality	493.000 €(183,6€:m²) for control system €3.800 (1,4€/m²) additional investment cost for LED lighting instead of conventional bulbs	
Legacy Civic Towers San Jose	III	1B	US	18,674m²	1997	Reduction	€7.473 annual energy saving	Reductio n	Increas ed indoor	€27.636 (1,5€/m²) for sensor installation	

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
							20% energy reduction possible for old buildings		air quality	18.048 (0,97€/m²) euro for computer modelling €13.724 (0,73€/m²) for energy managemen t system	
SD Worx office	III	1E	Belgium	1,350m²	2001	Reduction	29% reduction of primary energy use	27% reduction of CO2 emission s		€54.209 (40,15€/m²) for heat pump	
Centraal Besturingsgebo uw Dijlevalei	III	1B/1C/1D /1E	Belgium	708m²	2008	Reduction	Reduction expected by control system	Reductio n	Increas ed comfort	± €300 for Blowerdoor	
Test Classrooms Technology Campus	IV	1B/1C/1D /1E	Belgium	2*140m²	2011	- yearly benefit between €470.26-1176.5 - Further reduction by commissioning & monitoring	40% reduction for fan energy consumption 32% reduction for ventilation losses for heating (compared with situation CAV) Further reduction by commissioni		Increas ed indoor air quality	€ 6.600 (23,6€/m²) NPV for demand control (15 year period)	

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
							ng & monitoring				
Office KU Leuven	IV	1D	Belgium	n/a	(2016)		± 30% of energy reduction for space heating (in this case study: fuel oil (= 6% reduction of overall operational energy)				
Case studies with qualitative cost/benefit data											
Low Energy Renovation Leuven	I	1C	Belgium	168m²	1960 (2017)		n/a		Increased comfort	€858 - 1029 for verification (blowerdoor + thermographic)	
John Cabot City Technology Center	IV	1B	UK	8,800m²	1993			Reduction in CO_2 emissions in comparison with EEO Yellow Book		n/a	

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
ICT3&4 offices Leuven	III	1E	Belgium	1,778 m²+ 4,974 m²	2010	Reduction	energy reduction by installation of heat pump	Reductio n		n/a	
Elizabeth Fry Building	IV	1B	UK	3,250 m²	1995	Reduction	Reduction expected by control system	Reductio n	Increas ed inner air quality		
Social neighbourhood Venning	II	1A/1C/1D /1E	Belgium	25,475 m²	1960	90% energy reduction for lighting (= 2,1% reduction overall energy bill)	Assumed reduction of 90% by installing LED		Increas ed comfort	Assumed around 3,3 €/m² for LED light bulbs €485-629 for airtightness testing/ housing unit	
Interviews											
Prof. Dr. Sven Bienert - Universität Regensburg	ALL	1A	France	n/a	existing				increase in property value (and rental price) as a result of energy retrofits.		
Lars Myhre - Norwegian Home Builders' Association	I/II	1B/1E	Europe	n/a	New		±5% reduction by heating control system 30-40% reduction in	reduction by control system and heat pump (greener		Air-to-air heat pump: €1500-2500 (1/2 needed for apartment)	

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construction (renocation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	other	Investment (in €)	Operations and maintenance (in €/year)
							future (over 10 years) when lower primary energy factors achieved.	energy source)			
Lars Myhre - Norwegian Home Builders' Association	I/II	1B/1E	Europe	n/a	Existing		±10-20% reduction by heating control system				
Other sources											
Aspen index	ALL	ALL		Moderate Climate Zone		Possible to calculate bill savings				Provides cost data for new buildings and renovation	
Websites of companies /consultancy firms	ALL	1C		Belgium						Air-tightness testing: € 485-€629 Thermographic survey: ±€400	

Only qualitative information — Quantitative data + own assumptions — Quantitative data

MO 2 – Resource efficient material life cycles

Table 4 Cost and benefits sources for MO 2- Resource efficient material life cycles

Name	Reference Building	Action	Location	Dwelling/ office size	Age of construction (renovation)	Reference Building **Environmental Benefits**	Costs **Investment costs**
Building case studies							
Case studies with qualitative cost/benefit data							
Almelo city hall	IV	(2A), 2B	Netherlands	n/a	New	Reduction of environmental impacts	n/a
Ardennes residential building	II	2B, 2D	France	n/a	New	Reduction of environmental impacts	n/a
Bisceglie residential building	II	2B	Italy	n/a	New	Reduction of environmental impacts	n/a
Aalborg barracks	III	2B, 2C	Denmark	n/a	New	Reduction of environmental impacts	n/a
Interviews (N/A)							
Jane Anderson	All	2A, 2B	EU	All	New	Reduction on embedded carbon can reach 25% with selection of lower carbon footprint elements	The reduction can be reached with nearly zero investment costs
Dave Cheshire	All	2D	EU	All	New	Practical elimination of on-site waste (consisting currently of up to 1/3 of total material used).	Widely using pre-fabricated timber frames can lead to reduced construction costs
Simon Sturgis	All	2A, 2B, 2C	EU	All	New	Embedded carbon reductions can be significant	Near-zero cost actions if implemented from the design phase
Lars Myhre	I/II	2B	EU	All	New	25% potential reduction in emissions from low CO^2 concrete.	
Lars Myhre	I/II	2C	EU	All	All	Proper maintenance can significantly prolong the life-span of buildings (nearly indefinitely). The technical lifespan of buildings is less important than the economical lifespan.	

Name	Reference Building	Action	Location	Dwelling/ office size	Age of construction (renovation)	Reference Building	Costs
						Environmental Benefits	**Investment costs**
Other sources							
WRAP 2007	ALL	2B	All	All	All	80% reduction of environmental impacts (from production of aggregates, not concrete altogether) with 100% use of recycled aggregates. 24% carbon reduction for concrete overall with recycled content best practice	
WRAP (Cutting embodied carbon in construction projects)	I, III, IV	2A, 2B	All	All	All	Aluminium-clad timber windows rather than aluminium framed double glazing curtain walling can bring 8% carbon savings for the total building in the case of an office building. Aluminium-clad timber windows rather than uPVC framed double glazed in a house can reduce the carbon footprint of the building by 1% Embedded carbon in internal doors is 3 kg/m^2 for all building types except for houses where it is 4 kg/m^2 Windows have an embedded carbon of 80 kg/m^2 (for a school) or 43 kg/m^2 (house) Total embedded carbon for all building elements is 1104 kg/m^2 (office), 810 kg/m^2 (school) and 600 kg/m^2 (house)	

Only qualitative information — Quantitative data + own assumptions — Quantitative data

MO 3 – Efficient use of water resources

Table 5 Cost and benefit sources for MO 3 - Efficient use of water resources

Source	Reference building	Actions	Location	Dwelling/office size	Age of construction (renovation)	Benefits		Costs
						Water Savings (m^3/person/year or %/household)	Water Bill Reduction (in €)	Investment (in €)
Building case								
Case studies with quantitative cost/benefit data								
New houses Five Trees in Liss	I	3A, 3B, 3E, 3F	United Kingdom		2008	20.08	42.6	5678.54
Old houses Horndean and Rowlands Castle in South Hampshire	I & II	3A	United Kingdom		1950-1970	29.315	143	1223.98
Luxury homes at Brookhill, Crookham Village in Sheffield	I	3B	United Kingdom	120-129 m^2	New	62		1888
Water savings devices and awareness in Italy	All	3A	Italy		All	30-50% water savings		
Modern residential accommodation at 39 William IV Street in London	II	3A, 3E, 3F	United Kingdom	76 m^2	1970 (2016)	44% water savings		
Commercial office space at 22 Ganton Street in Lon	III	3A, 3E, 3F	United Kingdom	11,670 m^2	1920 (1999 & 2004)	8% water savings with respect to the required 5m^3/person/year		
Delivering sustainable office buildings	III & IV	3A, 3B, 3D	United Kingdom	11,150 m^2	2010	2847–5014 m^3/building/year		78392.95

Source	Reference building	Actions	Location	Dwelling/office size	Age of construction (renovation)	Benefits		Costs
						Water Savings (m^3/person/year or %/household)	Water Bill Reduction (in €)	Investment (in €)
Water audits and leakage reductions by O2 Building services	III & IV	3D	United Kingdom		Unknown		100000	
Water and energy efficiency measures in office building Kantaatti	III & IV	3A, 3B	Finland	4,300 m^2	Old (Renovated)	41% water savings		
Interviews								
Dr. Kemi Adeyeye	All	Action Package	North-west Europe		New	30% savings		
Dr. Kemi Adeyeye	All	Action Package	North-west Europe		Old	Up to 50% savings		
Prof. Armando Silva Afonso	All	Action Package	Southern Europe		All	More than 30% savings		
Prof. Armando Silva Afonso	All	3A	Southern Europe		All	30% water savings		Pay-back 1 to 2 years
Prof. Armando Silva Afonso	I & II	3B	Southern Europe		All	15% water savings		Pay-back 10- 15 years
Prof. Armando Silva Afonso	III & IV	3D	Southern Europe		Old	10- 50% water savings		Pay-back 0,5- 2 years
Prof. Armando Silva Afonso	I & II	3E	Southern Europe		All			Pay-back 3 months
Prof. Zuzana Vranayová	All	Action Package	Eastern Europe		All		30%	
Prof. Zuzana Vranayová	All	3A	Eastern Europe		All	30% water savings		

Source	Reference building	Actions	Location	Dwelling/office size	Age of construction (renovation)	Benefits		Costs
						Water Savings (m^3/person/year or %/household)	Water Bill Reduction (in €)	Investment (in €)
Prof. Zuzana Vranayová	I & II	3B	Eastern Europe		All			3000, with Pay-Back 18-20 years
Cath Hassel - ech2o consultants ltd & Anonymous water providers	I & II	3D	United Kingdom		Old	8% water savings		97 per visit
Cath Hassel - ech2o consultants ltd & Anonymous water providers	I & II	3E, 3F	United Kingdom		All			55
Other sources								
Collaboration of 300 municipalities for water efficiency in France	I & II	3A	France		All			Cost/benefit ratio 0,15
Collaboration of 300 municipalities for water efficiency in France	I & II	3B	France		All			Cost/benefit ratio 9-17
Collaboration of 300 municipalities for water efficiency in France	I & II	3C	France		All			Cost/benefit ratio 6,6
The costs & benefits of moving to full water metering in the United Kingdom	I & II	3F	United Kingdom		All	8.395		193.3092

Source	Reference building	Actions	Location	Dwelling/office size	Age of construction (renovation)	Benefits		Costs
						Water Savings (m^3/person/year or %/household)	Water Bill Reduction (in €)	Investment (in €)
Smart water metering in the United Kingdom	I & II	3F	United Kingdom		All	3,5% water savings		
Smart water metering in France	I & II	3B	France		All	5- 50 % water savings		
Smart water metering in France	I & II	3D	France		All	10-28 % water savings		
Smart water metering in France	I & II	3F	France		All	2-32 % water savings		

Only qualitative information

Quantitative data + own assumptions

Quantitative data

MO 4 – Healthy and comfortable spaces

Table 6 Cost and benefit sources for MO4 - Healthy and comfortable spaces

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construc-tion (renovation)	Benefits			Costs	
						Health improvements	Air quality	Productivity improvement	Investment/installation (in €)	Operations and maintenance (in €/year)
Building case studies - quantitative										
Simulations of the potential revenue from investments in improved indoor air quality in an office building	III / IV	4B	US	11,581m²	All	Improved health and performance	Reduction of VOCs	60 times higher than increased costs	pay-back time below 2.1 years	annual rate of return was 4-7 times higher than the minimum rate set at 3.2%
Simulations of the potential revenue from investments in improved indoor air quality in an office building	III / IV	4B	Cold climate (US)	11,581m²	All	Improved health and performance	Reduction of VOCs	133.60 €/m² floor/annual	119.38 €/m² floor	21.75 €/m² floor/annual
Simulations of the potential revenue from investments in improved	III / IV	4B	Moderate climate (US)	11,581m²	All	Improved health and performance	Reduction of VOCs	133.60 €/m² floor/annual	123,73 €/m² floor	22.40 €/m² floor/annual

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construc-tion (renovation)	Benefits			Costs	
						Health improvements	Air quality	Productivity improvement	Investment/installation (in €)	Operations and maintenance (in €/year)
indoor air quality in an office building										
Simulations of the potential revenue from investments in improved indoor air quality in an office building	III / IV	4B	Cold climate (US)	11,581m²	All	Improved health and performance	Reduction of VOCs	133.60 €/m² floor/annual	126.71 €/m² floor	24.344 €/m² floor/annual
Simulations of the potential revenue from investments in improved indoor air quality in an office building	III / IV	4A	US	11,581m²	All	Improved health and performance	Reduction of VOCs	26.64 €/m² floor/annual	5% higher building construction costs than a non-polluting building	
The development of low volatile organic compound emission house	I/II	Action Package	US		New built	Improved health and performance	Non-detectable to 43 µg m-3 total VOC concentration			

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construc-tion (renovation)	Benefits			Costs	
						Health improvements	Air quality	Productivity improvement	Investment/installation (in €)	Operations and maintenance (in €/year)
Cost-benefit of improved air quality in an office building	III / IV	4B	US	11,581m²	Renovation		Reduction of VOCs	1.1% increase in productivity for each 10% decrease in the percentage dissatisfied with air quality result in an economic benefit of €0.184 /hour per person.	4 months pay-back time	
Indoor Climate and Productivity in Offices	III / IV	4B	All Europe		All	Improved health and performance	Reduction of VOCs	44 €/m² floor/annual by 2% increased productivity	272 €/m² floor/annual with 10% interest rate and lifetime of investment of 10 years	
Interviews										
Pawel Wargocki	All	Action Package	N./C.Europe			Improved health and performance	Reduction of VOCs	Improved productivity		
Kasper Lynge Jensen	I/II	Action Package	N./C.Europe			Improved health and performance Reduced risk of asthma and allergies	Reduction of VOCs			

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construc-tion (renovation)	Benefits			Costs	
						Health improvements	Air quality	Productivity improvement	Investment/installation (in €)	Operations and maintenance (in €/year)
Kasper Lynge Jensen	III / IV	4B	N./C. Europe		Renovation	Improved health and performance	Reduction of VOCs	1-3%	200 €/m² floor for central ventilation system	30-40 €/m² floor/annual consumption 200 € annual maintenance
Kasper Lynge Jensen	III / IV	4B	N./C. Europe		Renovation	Improved health and performance	Reduction of VOCs	1-3%	132.5 €/m² floor for de-central ventilation system	
Kasper Lynge Jensen	I/II/ III/IV	4C	N./C. Europe		New built	Improved health and performance Reduced risk of asthma and allergies	Reduction of VOCs	Improved productivity		
Ruben Stuijk	I	4B	Belgium	280m²	2017 Intensive renovation	Improved health and performance Reduced risk of asthma and allergies	Reduction of VOCs		12.50 €/m² floor for simple ventilation system with mechanical extraction and natural intake	
Ruben Stuijk	I	4B	Belgium	220m²	2017 New built passive house	Improved health and performance Reduced risk of asthma and allergies	Reduction of VOCs		38.34 €/m² floor for mechanical intake and extraction with heat recovery	
Ruben Stuijk	III / IV	4B	Belgium	670m²	2014	Improved health and performance	Reduction of VOCs		44.03 €/m² floor for mechanical intake and extraction with heat recovery	
Ruben Stuijk	III / IV	4B	Belgium	733m²	2017 Renovation	Improved health and performance	Reduction of VOCs		34.11 €/m² floor for mechanical intake and extraction with heat recovery	

Source	Reference building	Actions	Location	Dwelling/ office size	Age of construc-tion (renovation)	Benefits			Costs	
						Health improvements	Air quality	Productivity improvement	Investment/installation (in €)	Operations and maintenance (in €/year)

Note: $ converted into € ($1= €0,93)

n/a No Data

Only qualitative information

Quantitative data + own assumptions

Quantitative data

MO 5 – Resilience to climate change

Table 7 Cost and benefit for MO 5 – Resilience to climate change

Source	Reference building	Actions	Location	Dwelling / office size	Age of construction (renovation)	Benefits				Costs		
						Thermal comfort (overheating degrees)	Energy savings	Health benefits	Productivity gains (€/year)	Investment	Operational costs (per year)	Maintenance costs (per year)
Case studies with quantitative data												
Cornwall	III/IV	5A	W. Europe	n/a	1960	0% increase due to climate change				50,000 - 67,000 € (11.5 – 15.5 €/m²)		
Cornwall	III/IV	5B	W. Europe	n/a	1960	0% increase due to climate change				128,000 – 138,000 € (29.5 – 32.0 €/m²)		
Cornwall	III/IV	5A	W. Europe	n/a	New build	0% increase due to climate change				39,000 € (12.0 €/m²)		
Cornwall	III/IV	5B	W. Europe	n/a	New build	0% increase due to climate change				166,700 € (51.4 €/m²)		
CREW detached	I	5B	W. Europe	n/a	Existing/new buildings	30-50% reduction in overheating exposure	Depending on variant, up to of heating energy 40%			2,600 - 15,000 € (18.5 - 107 €/m²)		
CREW detached	I	5C	W. Europe	n/a	Existing/new buildings	35% reduction in overheating exposure		Through improved air quality		minor security costs		
CREW apartment	II	5B	W. Europe	n/a	Existing buildings	30-60% reduction in overheating exposure	Depending on variant, up to of heating energy 40%			920 - 7,000 € (9.2 – 70.0 €/m²)		
CREW apartment	II	5C	W. Europe	n/a	Existing buildings	20-30% reduction in overheating exposure		Through improved air quality		minor security costs		
SD Worx office	III/IV	5D	W. Europe	1,350 m²	2001		29% energy use reduction			40,15 €/m²		
German Federal office Berlin	III/IV	5B	Central Europe	7,585 m²	2012	Decrease in discomfort hours by 41-50%				10,92 – 14,71 €/m²	0,78 – 3,77 €/m² (increase in lighting costs)	

Source	Reference building	Actions	Location	Dwelling / office size	Age of construction (renovation)	Benefits				Costs		
						Thermal comfort (overheating degrees)	Energy savings	Health benefits	Productivity gains (€/year)	Investment	Operational costs (per year)	Maintenance costs (per year)
Interviews												
Pawel Wargocki	III/IV	5A/ 5C	N. Europe		All buildings	Eliminate overheating feel		Through improved air quality	Significant productivity gains			
Kasper Jensen	III	5A/ 5C	All Europe		Existing	Eliminate overheating feel		Through improved air quality	1-3% productivity gains	5,300 €/unit (35.3 €/m²)	€ -15-25 €/m² (combined)	
Kasper Jensen	IV	5A/ 5C	All Europe		New build	Eliminate overheating feel		Through improved air quality	1-3% productivity gains	200 €/m²	€ -15-25 €/m² (combined)	
Sven Bienert	ALL	ALL	North, West and Central Europe		All buildings	Negligible property value increases due to increased resilience						
Lars Myhre	ALL	5D	All Europe		All buildings	Eliminate overheating feel	Reduce cooling energy consumption by 30-40%			1,500-2,500 €/unit (15-25 €/m²)		
Juan Lafuente	ALL	ALL	All Europe		All buildings	Achieving a 50% reduction in overheating seems reasonable	Significant reductions in cooling costs					
Other sources												
Wargocki and Djukanovic paper	III/IV	5A	North and Central Europe		New buildings				28.6 – 114.3 €/m²		1.0 €/m²	4.1 €/m²
Wargocki and Djukanovic paper	III/IV	5A	North and Central Europe		Existing buildings				28.6 – 114.3 €/m²		1.4 €/m²	6.5 €/m²

Source	Reference building	Actions	Location	Dwelling / office size	Age of construction (renovation)	Benefits				Costs		
						Thermal comfort (overheating degrees)	Energy savings	Health benefits	Productivity gains (€/year)	Investment	Operational costs (per year)	Maintenance costs (per year)
Wargocki and Djukanovic paper	III/IV	5A	W. Europe		New buildings				28.6 – 114.3 €/m²		0.7 €/m²	6.1 €/m²
Wargocki and Djukanovic paper	III/IV	5A	W. Europe		Existing buildings				28.6 – 114.3 €/m²		1.1 €/m²	7.7 €/m²
Wargocki and Djukanovic paper	III/IV	5A	S. Europe		New buildings				28.6 – 114.3 €/m²		1.4 €/m²	5.3 €/m²
Wargocki and Djukanovic paper	III/IV	5A	S. Europe		Existing buildings				28.6 – 114.3 €/m²		1.9 €/m²	8.3 €/m²

Only qualitative information

Quantitative data + own assumptions

Quantitative data

MO 6 – Optimised life cycle cost and value

Table 8 Cost and benefit sources for MO 6 – Optimised life cycle cost and value

Source	Reference building	Actions	Location	Dwelling /office size	Age of construction (renovation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	Other	Investment (in €)	Operations and maintenance (in €/year)
Building case											
Case studies with quantitative cost/benefit data											
Sustainable Neighbour-hood Waregem	I/II	6A/6C	Belgium	190 m^2	2016			Reduction due to material choice		€400-600 for user guide (as part of post-intervention file)	
Building 2226	III	6A/6B /6C/6 D	Austria	2,700 m^2	2014	Reduction due to no maintenance for heating or cooling system and no operational cost for heating or cooling	Reduction as no heating or cooling system applied	Reduction as no heating or cooling system applied		€493.000 (182,6€/m²) for control system	
Legacy Civic Towers San Jose	III	6B	US	18,647 m^2	1997	€7.473 (0,4€/m²) annual energy saving (in general terms: reduction of 20% energy bill)	20% reduction (i.e. possible for old buildings)	Reduction		€27.636 (1,5€/m²) for sensor installation €18.048 (0,97€/m²) for computer modelling €13.724 (0,73€/m²) for energy management system	

Source	Refe-rence buil-ding	Actions	Loca-tion	Dwelling /office size	Age of construction (renovation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	Other	Investment (in €)	Operations and maintenance (in €/year)
Test Clasrooms Technology Campus	IV	6B	Belgium	2011	2*140 m^2	-Energy cost reduction between 470,26 (1,7€/m²) - 1176,50 € (4,2€/m²) - Further reduction by commissioning & monitoring	-40% reduction for fan energy consumption 32% reduction for ventilation losses for heating (compared with situation CAV (continuous air ventilation)) -Further reduction by commissioning & monitoring	Reduction		€ 6.600 (23,6€/m²) NPV for demand control (15 year period)	
High building square Zelzate	II	6A	Belgium	6,800 m^2	2017	Life cycle cost: reduction of 16% (inner floor) & 2% (outer wall) Maintenance cost: reduction of 58% (inner floor) & 33% (outer wall) Replacement cost: increase of 64% (inner floor) &		Life cycle: reduction of 34% (inner floor) & increase of 14% (outer wall) Maintenance: reduction of 86% (inner floor) & 35% (outer wall) Replacement: reduction of 63% (inner floor) & 18% (outer wall)		inner floor: 232,8 €/m² floor outer wall: 172,76€/m² wall	

Source	Reference building	Actions	Location	Dwelling /office size	Age of construction (renovation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	Other	Investment (in €)	Operations and maintenance (in €/year)
						reduction of 49% (outer wall)					
Case studies with qualitative cost/benefit data											
John Cabot City Technology Center	IV	6B	UK	8,800 m^2	1993	Reduction		Reduction			
Interviews											
Dr. Mieke Vandenbroucke (VUB)	All	6D	W. Europe		New	Reduction on long-term		Reduction	On mid-term decrease of time for design process	Increased time needed in the beginning for designer Possible increase of investment cost	
Prof. Bienert (IREBS)	All	Action Package	Europe		New				Increase of property and rental value by 5-10% if significant energy savings are achieved		
Lar Myhre	I/II	6C	Europe	n/a	Existing/New				The life expectancy of building elements can be significantly		

Source	Refe-rence buil-ding	Actions	Loca-tion	Dwelling /office size	Age of construction (renovation)	Benefits				Costs	
						Bill saving	Energy savings	GHG reduction	Other	Investment (in €)	Operations and maintenance (in €/year)
									prolonged through preventive maintenance		
Other sources											
Aspen index	ALL	ALL	Moderate Climate Zone		New & Old	Possible to calculate bill savings				Provides cost data for new buildings and renovation	

Only qualitative information

Quantitative data + own assumptions

Quantitative data

Annex III Energy consumption

Baseline for MO1 for residential buildings

The baseline for residential buildings is defined as the yearly average energy consumption/m² floor are, differentiating between four zones (i.e. Western+Centre, Northern, Southern and Eastern) in Europe. These average annual energy consumptions per zone are calculated based on the yearly energy consumption for each EU Member States. This data is available from the EU Building Factsheets and apply to 2013.

More specifically, the average per zone is calculated as the sum of the energy consumption of all countries in that zone, divided by the number of countries. No differentiation is made between detached houses and apartments. The baseline values for detached houses and apartments are summarised in the table below.

Table 9 Energy consumption in residential buildings across Europe (2013)

Country	Energy Consumption [kWh/m²,year]
EU-28	184,14
Western + Centre	
Belgium	262,71
Netherlands	152,48
UK	182,10
France	190,16
Luxembourg	205,42
Ireland	165,68
Austria	198,46
Germany	199,73
Northern	
Lithuania	204,42
Latvia	292,28
Estonia	289,59
Finland	248,49
Sweden	214,81
Denmark	168,69
Southern	
Portugal	69,61
Spain	103,04
Malta	46,62
Greece	120,80
Cyprus	69,45
Italy	174,99

Country	Energy Consumption [kWh/m²,year]
Eastern	
Hungary	149,98
Poland	237,60
Romania	308,09
Slovakia	172,98
Slovenia	228,40
Bulgaria	121,09
Czech Rep.	234,40
Croatia	249,57

Source: European Commission,2013. EU Buildings Factsheets.

Baseline for MO1 for office buildings

For office buildings, the average yearly energy consumption for office buildings is not available for every EU Member State as is the case for residential buildings. For office buildings, the baseline is therefore calculated in a different way and is based on the yearly energy consumption for non-residential buildings across Europe from the ENTRANZE [1]project for 2008 combined with data available specifically for office buildings in a few European countries for 2009[2] as presented in the table below.

Table 10 Energy consumption in non-residential buildings across Europe (2008)

Country	Energy consumption [kWh/m²,year]
Western	
Belgium	554,00
Netherlands	326,00
UK	277,00
France	238,00
Luxembourg	997,00
Ireland	469,00
Austria	345,00
Germany	255,00
Northern	
Lithuania	244,00
Latvia	445,00
Estonia	443,00
Finland	299,00
Sweden	304,00
Denmark	196,00
Southern	
Portugal	230,00
Spain	311,00
Malta	210,00
Greece	198,00
Cyprus	366,00
Italy	590,00

1 Policies to **EN**force the **TRA**nsition to **N**early **Z**ero **E**nergy buildings in the EU-27 supported by the Intelligent Energy Europe programme.

2 Economidou, M., Atanasiu, B., Despret, C., Maio, J., Nolte, I., & Rapf, O. (2011). Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings. *Buildings Performance Institute Europe (BPIE)*.

Country	Energy consumption [kWh/m²,year]
Eastern	
Hungary	348,00
Poland	230,00
Romania	401,00
Slovakia	623,00
Slovenia	221,00
Bulgaria	171,00
Czech Rep.	424,00
Croatia	263,00

Source: ENTRANZE project by the European Commission.

Annex IV Water consumption

Water Usage

Different sources have been considered in the identification of the water consumption levels of residential and office buildings.

Average usage

The table below provides an insight in the domestic usage per capita across the EU[3] for the domestic sector, i.e. the water usage in residential and commercial buildings from the period 2009-2013 with respect to domestic activities (e.g. toilet flushing, tap water, washing, in-building leakages etc.). This table shows a clear variety in water usage across the different countries. This diversity is seemingly explained by the main general drivers of water consumption, number of occupants with in general lower l/p/d water usage for larger households, income, and climate conditions4 , as the water usage is generally higher in the more Southern and wealthier EU countries.

Table 11 Use of water by the domestic sector (households and services) - (m^3 per inhabitant)

Country	2008	2009	2010	2011	2012	2013
Western						
Belgium	26,4	26,0	26,0	20,9	:	:
Netherlands	54,0	53,7	53,4	52,9	52,8	:
United Kingdom	:	:	:	55,2	:	:
Northern						
Lithuania	29,1	28,1	28,1	29,1	*35,2*	:
Norway	*100,5*	*101,7*	:	:	:	:
Southern						
Portugal	57,0	59,6	:	:	:	:
Greece	:	:	:	82,5	:	:
Spain	*79,5*	*76,5*	*72,6*	*69,5*	*70,0*	:
Malta	*60,2*	*54,9*	*57,0*	*58,2*	*60,6*	*60,8*
Eastern						
Hungary	:	:	39,0	39,0	39,2	38,2
Poland	36,4	35,9	36,0	36,0	35,9	35,5
Slovenia	:	:	:	:	49,0	47,1
Bulgaria	46,4	45,5	44,9	45,3	46,1	46,9
Serbia	60,2	59,3	58,4	60,0	59,9	59,3
Bosnia and Herzegovina	32,5	33,0	33,2	33,7	*34,0*	32,2
Kosovo	:	:	:	26,2	26,6	:
Centre						
Switzerland	:	:	:	:	*119,3*	:

Source: Eurostat, water statistics, accessed at 02/02/2017:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wat_cat&lang=en.

Residential water usage

The report of European Commission (DG ENV- 2009) provides an overview of the average water household usage across EU countries identified in a number of studies. The table below present

3 Countries without data in the period 2009-2013 are omitted.

4 European Commission (DG ENV), 2009:*Reference: 07307/2008/520703/ETU/D2 Study on water performance of Buildings.*

this overview and seemingly confirms the tendency of more Southern countries to slightly more. However, from these data no strong correlation appears between wealth or climate with water usage.

Table 12 Average household water consumption (l/household/d)

Country (location)	Average household consumption (l/household/d)
Southern	
Cyprus (all areas)	174
Portugal (Guadiana)	210
Portugal (Algarve)	184
Italy (Sardinia)	175
Eastern	
Bulgaria (Sofia)	133
Bulgaria (Sofia)	186
Poland (Bytom)	123
Poland (Sosnowiec)	178
Western	
England (Portsmouth)	153

Source: European Commission (DG ENV), 2009:*Reference: 07307/2008/520703/ETU/D2 Study on water performance of Buildings.*

Breaking down the types of water consumption further provides some detail on the average usage of different types of consumption.

Moreover the report provides insight for some countries where this usage can be contributed to. Generally toilet flushing, showering are the most prominent sources of water usage. The usage via taps are the washing of clothes come thereafter and are of a similar magnitude. Finally dishwashers and outdoor use are of less significance. The table below provides an overview of the commonly consumption per water-using-product (WuP).

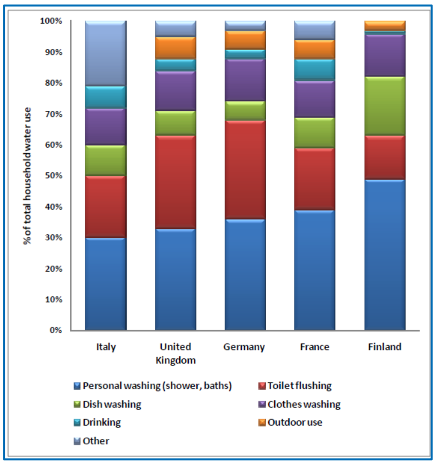
Table 13 Average water consumption per day (l/household/day) per water using product

WuP	Average water consumption (litres) per use	Frequency of use per day	Average water consumption per day (l/household/day)
WCs	6,0-9,5 /flush	7,0- 11.6	101.8
Showers	25,7 -60l /shower	0.75 – 2.5	91.8
Taps	2,3-5,8 /use	10.6 – 37.9	74.6
Clothes washers	39,0- 117 / use	0.6 -0.8	65.6
Dishwasher	21,3 -47,0 /use	0.5 – 0.7	24.3
Outdoor use	0-48,8/ use	0/ 0.89	21.8

Source: European Commission (DG ENV), 2009:*Reference: 07307/2008/520703/ETU/D2 Study on water performance of Buildings.*

Toilet flushing accounts in general for a significant share of the water consumption, but appears to be less in Southern Countries (Italy and Portugal), expectantly due to a lower number of flushes. On the other hand Toilets in Northern Countries (Finland) appear to be more efficient for which the proportionate usage is also lower.

Table 14 Distribution of water consumption across appliance and for toilets specifically



Country	Average water consumption per flush (litres)	Frequency of toilet flushing (per day)	Average total water consumption per day (litres)
England	9.4	11.62	109.2
Bulgaria	9.5	12.5	118.8
Portugal	9.1	9.3	84.8
Finland	6.0	-	-

Source: European Commission (DG ENV), 2009:*Reference: 07307/2008/520703/ETU/D2 Study on water performance of Buildings.*

Regarding showering the report sheds some light on the diversity between the United Kingdom, Portugal, Finland and Germany. The table below also explains the high share of personal washing in Finland as it has the highest water consumption per shower use.

Table 15 Average water consumption of showering

Country	Average frequency of use (use/household/day)	Average water consumption per use (l/shower)
United Kingdom	1.43	30- 505
Portugal	2.5	58.4
Germany	-	30-50
Finland	-	60
EU	0.75- 2.5	25.7 - 60

Source: European Commission (DG ENV), 2009:*Reference: 07307/2008/520703/ETU/D2 Study on water performance of Buildings.*

The above data considered one would expect that different actions have different effect in different geographic regions. More efficient toilets are for example more effective in the United Kingdom, Bulgaria, France and Germany, while more efficient shower butts can be make a significance difference in Finland, Portugal and France.

Office usage

European Commission (DG ENV- 2009) finds an moderate size office building of 10.000 $m^2$to consume over 20.000 litres a day (about 40 average size households) and notes that offices often still have a savings potential up to 30% these days. In terms of water usage per year this is a comparison of a standard practice with 9,3 m^3/p/y with a best practice 6,4 m^3/p/y. The CIRIA (2005) further specifies that an office building with a consumption of 4,0 m^3/employee/year is about average (16 litres/employee/day).

Differences among building types

The following section describes differences in consumption across the four building types.

5 30 is efficient new-built and 50 non-efficient new build.

Residential Buildings

Studies delineating the difference between blocks of flats, and detached and semi-detached houses have been identified for four countries. These include two European countries (Greece and Spain) and the USA and Australia.

In summary the four country studies provide the following insights: In all cases consumption was found to be in lower in apartments (blocks of flats) than in semi-detached or detached houses. Furthermore, consumption is also consistently found to be lower in semi-detached than in detached houses.

The table below provides and overview of the usage per building type and provides and indexation of the differences in water usage, with the block of flats taken as a baseline (100). For flats and semi-detached houses this difference is about 20 percent points, while their difference with detached houses is found to be quite diverse (6 to 326 percent points).

Table 16 Water usage per residential building type

Country	Block of flats	Semi-detached	Detached	Unit
Greece	0.32	*no value*	0.34	m^3 /house/day
	100	*no value*	106.25	Index
USA	0.416	*no value*	0.567	m^3 /house/day
	100	*no value*	136.2981	Index
Spain	0.3225	0.3875	1.052	m^3 /house/day
	100	120.1550388	326.2016	Index
Australia	0.490410959	0.619178082	0.761644	m^3 /house/day
	100	126.2569832	155.3073	Index

Source: based upon: Morote, A.F, Hernández M., and Rico A.M (2016), Causes of DomesticWater Consumption Trends in the City of Alicante: Exploring the Links between the Housing Bubble, the Types of Housing and the Socio-Economic Factors, Water 2016, 8, 374; Gratziou, M., Andreadaki, M. and Tsalkatidou, M. (2006), Water demand and reates policy in provincial Greece, European Water 15/16:33-44; Troy, P., Holloway, D., and Randolph, B., Water Use and the Built Environment: Patterns of Water Consumption in Sydney, City Futures Research Centre Research Paper No. 1.

Office Buildings

No evidence is found to expect the water usage for a public or a private office building differs.

Annex V EU building stock

Table 17 presents an aggregate overview of the EU buildings stock classified under the 4 reference building types of this study. This dataset categorises EU buildings by location (region), year of construction and by building type. This overview builds upon data and estimates for all 28 EU MS presented further down. The tables in this section present the number of dwellings for reference buildings I and II and the number of building for reference buildings III and IV.

Table 17 EU Building stock statistics

		B I Detached houses/SFH	B II Apartments/	B III Private offices	B IV Public offices
Western Europe	*Until 1945*	9,087,377	1,630,071	216,257	99,891
	1946-1979	11,298,637	1,676,180	480,413	126,608
	1980-2000	8,831,951	1,207,528	170,700	78,762
	after 2000	4,064,031	644,648	58,319	23,830
Subtotal		33,281,996	5,158,427	925,689	329,091
Northern Europe	*Until 1945*	1,421,428	1,364,845	63,577	13,969
	1946-1979	2,787,622	2,971,874	109,353	44,720
	1980-2000	1,099,225	1,353,286	63,192	28,439
	after 2000	490,844	571,151	22,725	15,863
Subtotal		5,799,119	6,261,156	258,847	102,991
Central & Eastern Europe	*Until 1945*	3,600,789	799,065	143,410	59,851
	1946-1979	8,916,262	3,312,778	257,267	86,151
	1980-2000	4,536,594	1,422,146	149,223	38,459
	after 2000	1,840,499	611,576	116,020	18,889
Subtotal		18,894,144	6,145,565	665,920	203,350
Southern Europe	*Until 1945*	4,784,871	2,408,196	128,631	75,255
	1946-1979	8,962,170	6,353,029	176,898	131,560
	1980-2000	5,806,551	3,498,744	139,465	99,065
	after 2000	1,735,773	1,393,914	63,626	14,731
Subtotal		21,289,364	13,653,883	508,620	320,610
Total		**79,264,624**	**31,219,031**	**2,359,076**	**956,042**

Source: Episcope/TABULA, EU Buildings database, Own calculations.

The classification of MS in regions can be seen in Table 18. The two main sources used to compile this dataset are the Episcope/TABULA6 Country Pages (available for most MS), combined with the EU buildings database7. In a number of cases the EU buildings database provided the age distribution of buildings in each category while the Episcope/TABULA database was used for the overall amount of buildings. Further, the report *Europe's buildings under the microscope8* shows that 25% of the total number of buildings are non-residential buildings. In the same report it is stated that 23% of the total non-residential buildings are offices, in come MS, where the absolute number of offices was lacking, the above assumptions have been used to extrapolate an estimate.

6 http://episcope.eu/index.php?id=197.
7 http://ec.europa.eu/energy/en/eu-buildings-database.
8 https://europeanclimate.org/documents/LR_%20CbC_study.pdf.

Table 18 EU building stock statistics per MS

Country	Region	Age	Detached house	Apart-ment	Private office	Public office	Note
Austria	Central & Eastern Europe	*Until 1945*	269,085	20,223	42,816	7,759	1
		1946-1979	577,901	29,503	51,395	9,314	
		1980-2000	395,658	10,624	18,393	3,333	
		after 2000	204,797	6,383	1,897	344	
Belgium	Western Europe	*Until 1945*	1,184,414	596,728	17,104	1,353	2
		1946-1979	1,281,469	645,626	27,587	2,182	
		1980-2000	600,006	302,293	12,095	957	
		after 2000	400,004	201,529	8,064	638	
Bulgaria	Central & Eastern Europe	*Until 1945*	433,859	4,194	4,158	659	1
		1946-1979	969,434	31,075	9,497	1,504	
		1980-2000	295,779	21,038	3,007	476	
		after 2000	74,144	13,023	827	131	
Croatia	Central & Eastern Europe	*Until 1945*	120,336	126,008	291	2,738	2
		1946-1979	451,707	472,999	2,402	9,201	
		1980-2000	247,164	258,815	1,328	3,719	
		after 2000	121,653	127,388	1,540	2,102	
Cyprus	Southern Europe	*Until 1945*	unknown	unknown	unknown	unknown	1
		1946-1979	58,524	13,524	1,445	488	
		1980-2000	78,420	31,493	2,107	711	
		after 2000	38,883	25,109	1,217	411	
Czech Republic	Central & Eastern Europe	*Until 1945*	375,300	35,200	15,607	1,027	1
		1946-1979	350,100	87,100	17,185	1,131	
		1980-2000	304,933	32,667	13,479	887	

Country	Region	Age	Detached house	Apart-ment	Private office	Public office	Note
		after 2000	170,867	10,133	5,868	386	
Denmark	Northern Europe	*Until 1945*	434,136	55,880	19,953	2,636	1
		1946-1979	562,121	18,435	21,489	2,839	
		1980-2000	127,005	8,647	7,595	1,003	
		after 2000	80,361	5,027	4,333	572	
Estonia	Northern Europe	*Until 1945*	29,231	85,527	1,592	1,420	2
		1946-1979	79,944	233,905	1,450	1,293	
		1980-2000	42,996	125,801	878	783	
		after 2000	16,309	47,718	720	643	
Finland	Northern Europe	*Until 1945*	142,568	189,748	1,125	5,812	2
		1946-1979	487,922	649,391	4,102	21,188	
		1980-2000	344,539	458,558	3,681	19,013	
		after 2000	189,625	252,377	1,972	10,187	
France	Western Europe	*Until 1945*	3,930,238	195,000	90,579	25,111	1
		1946-1979	3,563,212	246,200	93,299	25,865	
		1980-2000	3,522,340	63,800	54,091	14,995	
		after 2000	2,159,066	34,100	unknown	unknown	
Germany	Western Europe	*Until 1945*	2,427,000	29,300	26,707	61,886	1
		1946-1979	4,051,000	45,100	20,825	44,815	
		1980-2000	2,723,000	78,700	49,981	56,833	
		after 2000	775,000	49,600	13,677	19,836	
Greece	Southern Europe	*Until 1945*	275,708	224,307	unknown	unknown	2
		1946-1979	1,702,880	1,385,406	18,639	10,117	
		1980-2000	1,121,537	912,444	6,435	3,493	

Country	Region	Age	Detached house	Apart-ment	Private office	Public office	Note
		after 2000	640,825	521,353	5,897	3,201	
Hungary	Central & Eastern Europe	*Until 1945*	670,045	23,257	5,035	991	1
		1946-1979	1,121,341	31,919	9,154	2,372	
		1980-2000	577,880	16,449	16,477	1,402	
		after 2000	157,885	10,055	22,885	475	
Ireland	Western Europe	*Until 1945*	129,328	18,402	8,724	446	1
		1946-1979	184,109	17,199	9,389	480	
		1980-2000	199,400	37,422	3,584	183	
		after 2000	173,640	88,628	1,604	82	
Italy	Southern Europe	*Until 1945*	2,171,496	1,412,530	102,130	16,687	-
		1946-1979	3,185,142	3,040,128	121,789	19,899	
		1980-2000	1,280,156	1,161,984	83,443	13,634	
		after 2000	462,522	418,430	43,207	7,060	
Latvia	Northern Europe	*Until 1945*	71,427	165,095	594	506	2
		1946-1979	142,383	329,099	1,661	1,416	
		1980-2000	81,838	189,158	1,414	1,206	
		after 2000	18,871	43,618	190	162	
Lithuania	Northern Europe	*Until 1945*	156,654	128,745	unknown	unknown	2
		1946-1979	382,546	314,393	24,936	5,070	
		1980-2000	142,155	116,829	8,284	1,684	
		after 2000	26,168	21,506	4,748	965	
Luxembourg	Western Europe	*Until 1945*	23,810	19,641	1,982	84	2
		1946-1979	36,434	30,055	2,020	85	
		1980-2000	26,038	21,479	1,456	61	

Country	Region	Age	Detached house	Apart-ment	Private office	Public office	Note
		after 2000	33,488	27,624	711	30	
Malta	Southern Europe	*Until 1945*	16,150	25,735	unknown	unknown	2
		1946-1979	30,006	47,816	586	39	
		1980-2000	27,861	44,397	1,044	69	
		after 2000	18,853	30,042	779	362	
Netherlands	Western Europe	*Until 1945*	210,587	290,000	12,685	986	-
		1946-1979	230,413	302,000	30,962	2,408	
		1980-2000	340,000	537,000	29,370	2,284	
		after 2000	178,000	183,000	28,063	2,182	
Poland	Central & Eastern Europe	*Until 1945*	865,913	42,444	64,835	31,295	1
		1946-1979	1,778,721	71,649	148,195	29,164	
		1980-2000	1,220,761	57,310	89,534	19,139	
		after 2000	496,269	13,931	81,816	14,802	
Portugal	Southern Europe	*Until 1945*	575,740	399,708	12,575	3,712	2
		1946-1979	1,242,422	862,553	9,505	2,806	
		1980-2000	1,104,958	767,119	27,925	8,244	
		after 2000	574,690	398,980	12,526	3,698	
Romania	Central & Eastern Europe	*Until 1945*	583,580	401,121	7,128	15,282	2
		1946-1979	2,944,496	2,023,888	14,885	33,271	
		1980-2000	1,155,165	793,998	4,200	9,389	
		after 2000	526,213	361,690	277	618	
Slovakia	Central & Eastern Europe	*Until 1945*	142,067	145,687	88	276	2
		1946-1979	548,715	562,700	335	1052	
		1980-2000	224,693	230,420	187	587	

Country	Region	Age	Detached house	Apart-ment	Private office	Public office	Note
		after 2000	67,005	68,713	39	123	
Slovenia	Central & Eastern Europe	*Until 1945*	140,605	930	3,453	730	1
		1946-1979	173,847	1,945	4,219	892	
		1980-2000	114,561	826	2,617	553	
		after 2000	21,666	260	871	184	
Spain	Southern Europe	*Until 1945*	1,745,777	345,916	13,926	54,856	1
		1946-1979	2,743,195	1,003,602	24,933	98,211	
		1980-2000	2,193,619	581,307	18,511	72,914	
		after 2000	unknown	unknown	unknown	unknown	
Sweden	Northern Europe	*Until 1945*	587,412	739,850	40,313	3,594	2
		1946-1979	1,132,706	1,426,652	80,626	12,913	
		1980-2000	360,692	454,294	49,616	4,749	
		after 2000	159,511	200,905	15,505	3,334	
United Kingdom	Western Europe	*Until 1945*	1,182,000	481,000	58,475	10,026	1
		1946-1979	1,952,000	390,000	296,331	50,774	
		1980-2000	1,421,167	166,833	20,124	3,448	
		after 2000	344,833	60,167	6,200	1,062	
Note 1	For reference building II, the statistics refer to the number buildings instead of the as the number of dwellings.						
Note 2	The building age distribution was assumed to be similar between multi-family homes and single family homes (type I and II).						

The following table presents some fundamental properties attributed to average cases of the four reference buildings that have been selected:

Table 19 Specifications of the four reference buildings

	Reference Building I	Reference Building II	Reference Building III	Reference Building IV
Building typology	Residential - single family detached house	Low-rise apartment block (more than 10 dwellings)	Low-riser private office building (low specifications)	Public sector office building (similar to previous)
Size	approx. 140 m^2	approx. 100 m^2 (per apartment)	approx. 1,500 m^2	approx. 1,500 m^2
Constructor/ Initiator	Private promoter/investor build a housing estate of 5-10 houses	Public housing company or private investor	Private promoter/investor	Private constructor contracted by the public sector
Owner	Private owner - user, acquired on the open market	Private owner (same as initiator)	Private owner (same as initiator)	Public
Users	4-person family (also owner)	Residents of 10 apartments (in long-term rental)	5-10 individual companies renting space adjusted to their needs (total of approx. 100 employees)	1 public authority with approx. 100 employees.

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