CONTRIBUCIÓN A LA SOSTENIBILIDAD EN LA EDIFICACIÓN MEDIANTE EL DESARROLLO DE UNA METODOLOGÍA SIMPLIFICADA PARA EL CÁLCULO DE LA EFICIENCIA ENERGÉTICA Y DE SOSTENIBILIDAD DE UNA VIVIENDA

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Tesis Doctoral

Contribución a la sostenibilidad en la edificación mediante el desarrollo de una metodología simplificada para el cálculo de la eficiencia energética y de sostenibilidad de una vivienda.

Jordi Castellano Costa
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El Dr. Joaquim de Ciurana, catedràtic del Departament d'Enginyeria Mecànica i de la Construcció Industrial de la Universitat de Girona i el Dr. Albert Ribera, Titular d'Escola Universitària del Departament d'Arquitectura i Enginyeria de la Construcció.

CERTIFIQUEN:
Que aquest treball, titulat "Contribución a la sostenibilidad en la edificación mediante el desarrollo de una metodología simplificada para el cálculo de la eficiencia energética y de la sostenibilidad de una vivienda", que presenta Jordi Castellano Costa per a l'obtenció del títol de doctor, ha estat realitzat sota la nostre direcció i que compleix els requeriments.

Signatura

Girona, 15 d'octubre de 2016

Per la meva dona i els meus fills.

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LISTA DE PUBLICACIONES

Esta tesis Doctoral es presentada como un compendio de artículos científicos. La siguiente lista contiene las publicaciones presentadas como capítulos de esta Tesis.

CAPÍTULO 3: Castellano, J., Castellano, D., Ribera, A., Ciurana, J.,(2014). Development of a scale of building construction systems according to CO2 emissions in the use of their life cycle. Building and Environment, 82,618-627.

2014, la revista BUILDING AND ENVIRONMENT tiene un Factor de Impacto de 3.341.

Esta tabla muestra el ranking de la revista en su categoria de contenido basado en su Factor de Impacto.

Nombre de la categoría	*Total de revistas en la categoría*	*Posición dentro de la categoría*	*Cuartil en la categoría*
Engineering Civil	124	3	1Q

CAPÍTULO 4: Castellano, J., Castellano, D., Ribera, A., Ciurana, J.,(2015). Devoloping a simplified methodology to calculate CO2/m2 Emissions per year in the use phase of newly-built, single-family houses. Accepted in Energy and Buildings.

2015, la revista ENERGY AND BUILDINGS tiene un Factor de Impacto de 2.884.

Esta tabla muestra el ranking de la revista en su categoria de contenido basado en su Factor de Impacto.

Nombre de la categoría	*Total de revistas en la categoría*	*Posición dentro de la categoría*	*Cuartil en la categoría*
Engineering Civil	124	6	1Q

CAPÍTULO 5: Castellano, J., Ribera, A., Ciurana, J.,(2015). A methodology and tool for a sustainable housing assessment. Submitted in Journal of Cleaner Production.

2015, la revista Journal of Cleaner Production tiene un factor de impacto de 3.844.

Esta tabla muestra el ranking de la revista en su categoria de contenido basado en su Factor de Impacto.

Nombre de la categoría	*Total de revistas en la categoría*	*Posición dentro de la categoría*	*Cuartil en la categoría*
Engineering Environmental	47	8	1Q

LISTA DE SÍMBOLOS

A,B...G	Escala de clasificación eficiencia energética
CO2	Dioxido de Carbono
CO2/m2	Emisiones de dióxido de carbono por unidad de superfície
CO2eq	Unidad de medida equivalente de los gases de efecto invernadero
CO2/E	índice de carbonatación
E	Energía
GDP	Gross Domestic Product
m2	Unidad de superfície
P	Population
R	Resistencia Térmica

LISTA DE ACRÓNIMOS

LCA	Life Cycle Assessment
ACV	Análisis Ciclo de Vida
BD+C	Building Design & Construction
BREEAM	Building Research Establishment Environmental Assessment Method
BUWAL	Green House Gas Protocol
CASBEE	Comprehensive Assessment System for Built Environment Efficiciency
Efficiciency	
CCV	Costes del Ciclo de Vida
CEE	Comunidad Económica Europea
DAP	Declaración Ambiental de Producto
DGNB	Deutsche Gesellschaft für Nachhalties Bauen
EPC	Energy Performance Certificate
EPBD	Energy Performance Building Directive
EPD	Environmental Product Declarations
EU	Unión Europea
GBCe	Green Building Council España
IBEC	Institute for Building Environment and Energy Conservation
ISO	International Organization Standardization
LCM	Life Cycle Management
LEED	Leadership in Energy and Environment Design
nZeb	Nearly Zero Emissions Building
PCR	Product Category Rules
RAE	Real Academia Española
PIB	Producto Interior Bruto
SAP	Standard Assessment Procedure
SETAC	Society of Environmental Toxicology and Chemestry
US-EPA	United State Environmental Protection Agency
USGBC	United States Green Building Council

LISTA DE FIGURAS

LISTA DE TABLAS

CONTENIDO

RESUMEN ***RESUM*** *SUMMARY*

El desarrollo de la sostenibilidad en la edificación ha realizado un gran avance en los últimos diez años, mejoras en la eficiencia energética de los edificios con la incorporación del certificado de eficiencia energética (EPC), el desarrollo del análisis del ciclo de vida de productos y servicios (LCA), la incorporación en el diseño de edificios con espacios más iluminados y saludables para vivir, trabajar y recrearse, junto con la aparición de certificaciones de evaluación de la sostenibilidad de los edificios; constituyen una realidad inspirando innovaciones en cuanto a materiales, productos y procesos.

Esta Tesis se centra en el desarrollo de herramientas que ayuden a los técnicos y a la población en general a adoptar criterios de sostenibilidad, mediante la aplicación de una metodología diseñada para la adopción de sistemas constructivos eficientes energéticamente y el cálculo de las emisiones de CO2 en una vivienda unifamiliar, junto con el desarrollo de una herramienta que facilite la elección de una vivienda lo más sostenible posible.

El desenvolupament de la sostenibilitat en la edificació ha realitzat una gran evolució en els últims 10 anys, millores en la eficiència energètica dels edificis amb la incorporació del certificat de eficiència energètica (EPC), el desenvolupament de l'anàlisi del cicle de vida de productes i serveis (LCA), la incorporació en el disseny d'edificis amb espais més il.luminats i saludables per viure, treballar y gaudir, juntament amb l'aparició de certificacions d'avaluació de la sostenibilitat dels edificis; constitueixen una realitat inspirant innovacions en materials, productes y processos.

Aquesta Tesis es focalitza en el desenvolupament de les eines que ajudin als tècnics i a la població en general a adoptar criteris de sostenibilitat, mitjançant l'aplicació d'una metodologia dissenyada per l'adopció de sistemes constructius eficients energèticament i el càlcul de les emissions de CO2 en un habitatge unifamiliar, juntament amb el desenvolupament d'una eina que faciliti la elecció d'una habitatge el més sostenible possible.

The development of sustainability in construction has made a breakthrough in the past decade, improvements in building's energy efficiency with the appearance of the energy performance certificate (EPC), the development of life-cycle analysis forgoods and services (LCA), the design of buildings with brighter and healthier areas where to live, work and play, along with the emergence of construction sustainability certifications; are a reality inspiring innovations in materials, products and processes.

This thesis focuses on the development of tools to help professionals and the general population to embrace sustainability criteria by applying a methodology designed to adopt energy efficient building systems and calculations of CO2 emissions in single family housing, along with the development of a tool that facilitates the choice of a housing as sustainable as possible.

1. DEFINICIÓN DEL TEMA DE INVESTIGACIÓN

1.1 Introducción a la Sostenibilidad en la Edificación

La definición de sostenibilidad por si misma genera diferentes apreciaciones en función del actor que la utiliza. Según la RAE, el término sostenibilidad significa cualidad de sostenible y sostenible significa que se pueda mantener por si mismo.. Se refiere al equilibrio de una especie con los recursos de su entorno.

En el año 1987 cuando la Comisión Mundial para el Medioambiente y Desarrollo de las Naciones Unidas definió mediante el Informe Brundland, definió el concepto de desarrollo sostenible como: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Komiyama y Takeuchi, (2006) definen el concepto de ciencia de la sostenibilidad con tres niveles de sistemas, global, social, y humano. El "global system" incluye el planeta tierra con un sistema comprendido por la geosfera, atmósfera, hidroesfera y bioesfera. Éste último es el que suministra a los humanos de los recursos naturales para su existencia. El "global system" se ve afectado directamente por el comportamiento de la especie humana, un ejemplo claro, es el cambio climático y la destrucción de la capa de ozono. El "social system" consiste en las estructuras político-económicas e industriales y otras creadas por el hombre para su organización, pero muchas veces estas estructuras crean problemas medioambientales y de crecimiento desigual entre los hombre (ricos y pobres). El último sistema recibe el nombre de "human system" que es la suma total de factores que afectan a la supervivencia del ser humano. Éste, según Komiyama H y Takeuchi (2006) está conectado directamente al sistema social, donde vivir saludablemente, seguros y sin peligros es el principal objetivo.

Por tanto se puede definir la sostenibilidad como un equilibrio entre los sistemas, global, social, humanos, si lo adaptamos a las características de la sostenibilidad de los edificios, un equilibrio entre los aspectos ambientales, económicos y sociales donde la salud y el bienestar es la principal categoría de impacto en este último sistema.

En una primera fase de construcciones, los edificios no se llamaban sostenibles si no verdes de alto rendimiento, que surgieron en respuesta a la demanda por mayor eficiencia energética y de recursos. Fué con posterioridad y con la llegada de herramientas de evaluación, que la industria de la edificación vió los edificios de una forma más holística teniendo en cuenta aspectos como la calidad del aire interior, mobilidad, emissiones, agua, bienestar etc…, junto con las ventajas económicas y sociales que poseen estos edificios.

1.2 Exposición del problema

Actualmente los estudios realizados y los artículos escritos sobre construcción sostenible son muchos y a la vez bastante clarificadores de cuales son los indicadores que se han de tener en cuenta para la realización de la edificación sostenible. Pues la gran pregunta es, ¿Porqué la gran mayoría de los promotores, inversores, Arquitectos, Ingenieros no siguen estos indicadores para construir edificios sostenibles?. La respuesta es muy sencilla, debido al abanico tan amplio de normativas tanto Estatales, como Autonómicas y Europeas. Estas han provocado contradicciones entre las mismas y a la vez muchas incongruencias, provocando una duplicidad de documentación y procesos de cálculo. Todo esto agravado por muchas definiciones de conceptos tan diferentes como bioconstrucción, arquitectura bioclimática, construcción ecológica, construcción sostenible y otros.

Otra problemática es la metodología a utilizar para evaluar los edificios sostenibles. Si se quieren medir los impactos ambientales generados por la construcción la metodología a utilizar es el Anális del ciclo de vida (ACV) del edificio, empezando por la fase de producción de los materiales, la construcción del edifico, los impactos generados por la fase de utilización, y al final por la fase de derribo. El problema es que no todas las herramientas de valoración ambiental utilizan los mismos criterios, ni tratan con la misma importancia las diferentes fases del ACV. Algunas de estas herramientas dan más importancia al uso y al mantenimiento y por al contrario otras dan más importancia a la producción de materiales o a la construcción (Wadel G et al., 2010).

Otra de las suposiciones, es que los edificios sostenibles son más costosos de construcción, cuando las investigaciones demuestran que las construcciones sostenibles no necesariamente son más costosas, especialmente si desde un comienzo se integran en el proceso el desarrollo de las estrategias económicas, una adecuada administración del programa y estrategias ambientales. (World Green Building Council 2013).

La lentitud y retraso de la aplicación de la Directivas Europeas en materia de eficiencia energética en nuestro país, la falta de comunicación a la población de los beneficios de la eficiencia energética y la falta de experiencia en la utilización de unas herramientas de simulación por parte de los técnicos han propiciado un daño difícil de cuantificar en el sector. Aunque internacionalmente en grandes edificios se ha comprobado que los edificios sostenibles permiten ahorrar dinero gracias a un menor consumo de energía y agua y a sus menores costos operacionales y de mantenimiento a largo plazo.
En cuanto a la productividad laboral y salud de los trabajadores los investigadores demuestran que el diseño sostenible de edificios puede mejorar la productividad laboral y la salud y bienestar ocupacional, a pesar de la evidencia de sus impactos, mejorar la calidad de los ambientes interiores no ha sido la prioridad en el diseño y la construcción de edificios. Es probable que esto se deba a que la “productividad” es compleja de medir.

1.3 Motivación

El principal objetivo de esta tesis es desarrollar los estudios y experimentos necesarios para mejorar el nivel de conocimientos en el ámbito de la sostenibilidad. Crear las herramientas y metodologias para el desarrollo de la edificación sostenible en las diferentes fases del ACV, concretamente en la fase de uso, mediante la implantación de sistemas constructivos energéticamente eficientes en la fase de diseño. También el desarrollo de una metodología que permita de una forma sencilla el conocimiento de las emisiones de CO2/m2 de una vivienda unifamiliar y para finalizar una herramienta que nos permita valorar la sostenibilidad de una vivienda por parte de un usuario.

Más específicamente, los objetivos de la tesis son:

- Investigar sobre el proceso del Análisis del ciclo de vida (ACV) en el sector de la construcción y evidenciar los impactos generados en cada fase del mismo.

- Investigar experimentalmente mediante diferentes programas de simulación sobre un caso de estudio el desarrollo de una metodología para la clasificación de los sistemas constructivos en función de su eficiencia energética y dotarles de una escala de clasificación.

- Investigar sobre la evolución e implantación de la Directiva de la Unión Europea (EU) de eficiencia energética en edificios (EPBD). Esto nos permitirá obtener información sobre el nivel de implantación de la misma y lo más importante los parámetros de la eficiencia de los edificios indicados mediante los certificados de sostenibilidad.

- Investigar experimentalmente mediante un caso de estudio la utilización de diferentes programas de simulación energética para la creación de una fórmula aritmética para cuantificar las emisiones de una vivienda unifamiliar y a la vez que sea comparable con los certificados de eficiencia energética (EPC), facilitando el cálculo de las emisiones.

- Analizar las certificaciones de sostenibilidad existentes, sus diferencias y similitudes. Aplicar las mismas sobre un caso de estudio consistente en un edificio plurifamiliar de viviendas.

- Desarrollar una herramienta, validada sobre el caso de estudio anterior que permita de una manera sencilla la evaluación de la sostenibilidad de una vivienda por parte de un usuario.

Los resultados obtenidos en esta tesis deberían servir como herramienta de ayuda a la toma de decisiones por parte de los equipos de diseño e Ingenieros para que se plateen la implantación de sistemas constructivos eficientes energéticamente así como la utilización de la metodología desarrollada para la construcción de viviendas unifamiliares.

Por otro lado la herramienta de sostenibilidad desarrollada, pretende influenciar a los usuarios en la compra o alquiler de viviendas sostenibles, diferenciándose de las herramientas de sostenibilidad actuales, focalizadas a las grandes inversores o promotores.

1.4 Metodología y ámbito de aplicación

La metodología seguida para la realización de esta tesis es la siguiente:

1. Análisis de la literatura y de los estudios realizados, tanto en el ámbito del análisis del ciclo de vida como del desarrollo de los cálculos de emisiones de CO2 de las viviendas mediante el desarrollo de las Directivas Europeas sobre eficiencia energética y la aplicación de criterios de sostenibilidad por las diferentes herramientas de certificación en sostenibilidad. Este análisis ha permitido el establecimiento de un marco teórico y la elaboración del estado del arte, así como también evaluar los resultados obtenidos en trabajos de investigación que abordan problemáticas diferentes sobre el análisis del ciclo de vida, la transposición de las Directivas Europeas en cada país y las diferencias entre las herramientas de sostenibilidad.

2. Análisis de las variables y parámetros de las herramientas de simulación de eficiencia energética que tienen influencia en la obtención de los datos de emisiones de CO2, así como la obtención de los parámetros de medición y clasificación de las diferentes herramientas de evaluación de la sostenibilidad. Clasificación de dichas variables.

3. Experimentación en base a casos de estudio, mediante herramientas de simulación para determinar el porcentaje de emisiones de los diferentes componentes del envolvente de un edificio y los sistemas constructivos que los componen, como el resultado global de emisiones de la totalidad de la vivienda. En el caso de la experimentación sobre la evaluación de la sostenibilidad de viviendas, se ha realizado la comparación mediante diferentes herramientas de los impactos ambientales analizados. Esta fase comprende las sub-fases siguientes:

a. Diseño del experimento o caso de estudio, para determinar que modelo es el más adecuado para el tipo de respuestas que se espera obtener y el número de variables de entrada.
b. Elaboración de hipótesis, donde se describen las condiciones y las características del experimento o caso de estudio así como la metodología seguida para minimizar los errores de simulación.
c. Realización de las pruebas para verificar que los resultados obtenidos están dentro de los rangos esperados y comprobar que las hipótesis y parámetros utilizados son adecuados. Realización de cambios y ajuste de parámetros.
d. Análisis de los resultados, para el desarrollo de los diferentes modelos y herramientas utilizados objetivo de la tesis.

4. Elaboración y desarrollo de los diferentes modelos y herramientas a partir de la información obtenida en el punto anterior.
El alcance de la tesis comprende la obtención de metodologías y herramientas con las limitaciones siguientes:

- En el desarrollo de la metodología sobre el sistema de clasificación de la eficiencia energética de sistemas constructivos, está validada en casas unifamiliares y en una tipología de clima.
- En el desarrollo de una metodología que nos ayuda a obtener una fórmula aritmética para la obtención de las emisiones de CO2 de una vivienda, está validada en casas unifamiliares y en una tipología de clima.
- En el desarrollo de una herramienta para la evaluación de la sostenibilidad, está limitada a la evaluación de viviendas y para la zona de Europa.

1.5 Estructura de la Tesis

La tesis que se presenta se estructura en 7 capítulos. El primero es una introducción a la tesis, el segundo capítulo consiste en la recopilación de información o estado de la cuestión para el desarrollo de la tesis, los capítulos 3,4 y 5 son los artículos científicos publicados y enviados para publicación, el 6 las conclusiones y el 7 las referencias.

Capítulo 1- Definición del tema de investigación
Se expone el tema de investigación y se resume la metodología utilizada en el desarrollo del trabajo.

Capítulo 2 - Introducción a la investigación
Un resumen del estado de la cuestión. Primero se analizan los conceptos de análisis del ciclo de vida en la construcción y normativa de referencia. En segundo lugar se revisa el estado de la implantación de la directiva de la UE sobre eficiencia energética en los edificios en Europa y la información sobre las emisiones de CO2. Tercero se analizan de las diferentes herramientas de evaluación de sostenibilidad de edificios.

Capítulo 3 - Artículo científico
sobre el desarrollo de una escala de clasificación de edificios en función de las emisiones de CO2.

Capítulo 4 - Artículo científico
en el que se desarrolla una metodología simplificada para el cálculo de las emisiones de CO2/m2 año en la fase de uso de viviendas unifamiliares de nueva construcción.

Capítulo 5 - Artículo científico
En el que se desarrolla una herramienta para la valoración de la sostenibilidad de las viviendas.

Capítulo 6 - Conclusiones y desarrollos futuros
Comprende una síntesis de las principales conclusiones, así como las discusiones sobre las mismas con el objetivo de plantear futuras líneas de investigación.

Capítulo 7 - Referencias
Contiene un listado de bibliografía y artículos consultados ordenados de forma alfabética.

Figura 1.1 Presenta la relación entre los diferentes capítulos de la tesis.

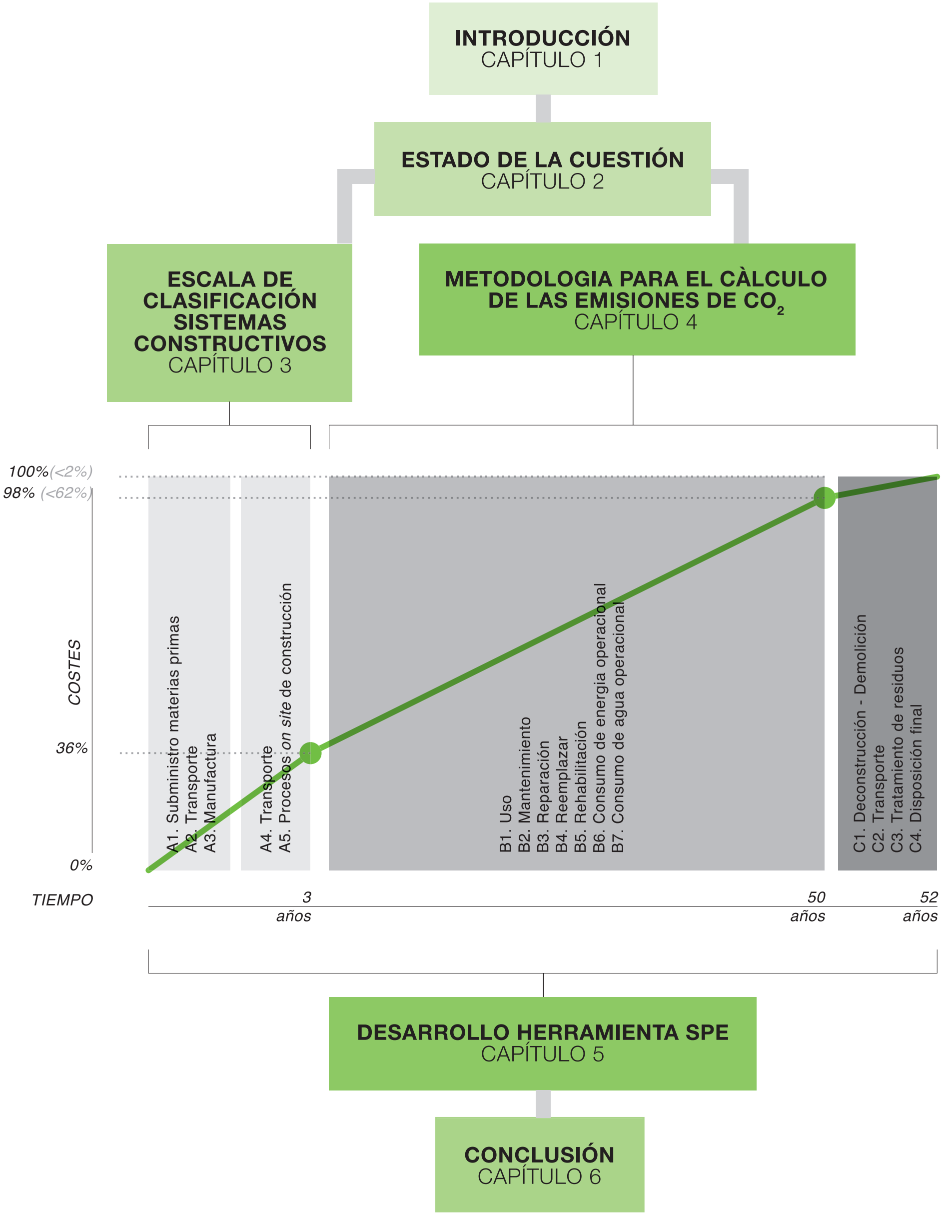


Figura: 1.1 Estructura de la Tesis.

2. INTRODUCCIÓN A LA INVESTIGACIÓN

El capítulo 2, lleva a cabo una revisión del estado de la cuestión de la tesis. En primer lugar se hace una revisión sobre el estudio del análisis del ciclo de vida. En segundo lugar el estado actual de la eficiencia energética en Europa y procedimientos para su evaluación y por último una revisión de la evolución y características de las diferentes herramientas de sostenibilidad del mundo.

2.1 Análisis del ciclo de vida (ACV)

2.1.1 Introducción al análisis del ciclo de vida

Hoy en día el mundo desarrollado es conocedor del impacto sobre el medio ambiente producido por el sector de la edificación en cualquier de las fases del ciclo de vida, Figura 2.1

Figura 2.1: Esquema de los módulos de información para las diferentes etapas del ciclo de vida. UNE EN 15978:2011

Por ejemplo se puede comprobar como en Suiza el sector de la edificación representa el 50% de consumo energético (Zimmermann et al., 2005) y a la vez como está distribuido este consumo dentro del sector. Igualmente Zöld and Szalay (2007), indican que el consumo energético en Europa está entre el 40% y el 50% y de la misma forma Erlandsson and Borg muestran que la demanda energética en el sector de la edificación es del 30-40%.

Respecto los recursos de los materiales utilizados en la construcción estos representan un 44% (Li Zhuguo et al., 2009). Igualmente, se puede confirmar que más del 50% de las materias primeras extraidas de la tierra se transforman para la construcción en productos y materiales.

Económicamente la construcción representa un 10% del PIB mundial en un año, siendo el 30% en Europa, el 22% en Estados Unidos, el 21% en el Japón, el 4% en el resto del mundo desarrollado (Ortiz O et al., 2009). Monetariamente en el 2004 representó en la EU-27 una producción total de 1.305 billones de euros.

Li Zhuguo et al. (2006) nos indican que el sector de la construcción es responsable de un 1/3 de las emisiones de CO2 , o también podríamos decir que en Europa el 35% de los gases de efecto invernadero proceden del sector de la construcción según se demuestra en un informe de la UE. Los residuos de la construcción y la demolición ascienden a más de 450 millones de toneladas por año en la EU.

Socialmente la construcción representa el 7,3% del total del Trabajo de la EU, sin tener en cuenta la industria manufacturera y los servicios posteriores a la construcción como pueden ser el mantenimiento de los edificios según la UE. El porcentaje de trabajadores sobre la industria manufacturera es del 29,1%.

Para analizar todos estas categorías de impactos a partir de los años 70 se empezaron a realizar los primeros estudios de ACV sobre productos concretos como eran los envases, pero no fue hasta finales de los años 90 que instituciones como SETAC, BUWAL, US-EPA, Nordic Council, ISO y otros empezaron a definir los procedimientos de estudio de ACV, hasta que a principios de los años 2000, ISO estableció la estandarización del ACV.

A partir de aquí empezaron a ser más frecuentes los estudios de ACV teniendo en cuenta las diferentes categorías de impacto, como pueden ser el potencial de calentamiento global, el agotamiento del ozono estratosférico, los potenciales de acidificación, potencial de eutrofización, potencial de formación de foto oxidantes, potencial de toxicidad humana, potencial de eco toxicidad, básicamente asociados al cambio climático (Ortiz et al., 2009).

Respecto al sector de la construcción podemos encontrar un estudio sobre LCM de Ortiz et al. (2009) que nos comunica que aproximadamente entre el 80-92% de los impactos ambientales corresponden a 6 categorías y se producían en la fase de uso. También es importante tener en cuenta el análisis en base ACV hecho por Zabalza et al. (2009), donde solo tiene en cuenta el análisis de energía primaria en la fase de uso y la energía embebida de los materiales, estos representan un 69% y el 31% respectivamente. Uno de los artículos más completos sobre sostenibilidad en el sector de la construcción es el de Ortiz , basados en conceptos, herramientas y alcance del ACV (Ortiz et al.,2009).

Importante mencionar la iniciativa de la Unión europea para el desarrollo de una metodología sobre el uso de métodos comunes para medir y comunicar el comportamiento ambiental de los productos y las organizaciones a lo largo de su ciclo de vida. (2013/179/UE).

2.1.2 Metodología del análisi del ciclo de vida

La metodología del análisis del ciclo de vida (ACV) se basa en las normas internacionales ISO 14044:2006 e ISO 14040:2006, y en el caso de la edificación se complementan con las UNE EN 15978:2011, y UNE EN5804. Actualmente en Europa la metodología a seguir es la que se basa en la recomendación de la comisión Europea sobre el uso de los métodos comunes para medir y comunicar el comportamiento ambiental de los productos y las organizaciones a lo largo de su ciclo de vida.
El análisis del ciclo de vida comprende cuatro etapas diferentes: La definición de los objetivos y ámbito o alcance de aplicación, el análisis del inventario, la evaluación del impacto y por último la interpretación de los resultados, Figura 2.2.

Figura 2.2: Interrelación entre las diferentes etapas de un ACV. Fuente: Comunidad de Madrid.

La definición de los objetivos y ámbito de aplicación implica definir el propósito, los límites del estudio sobre la edificación y el nivel de detalle. Esto puede venir determinado por razones de marketing, mejora de producto, razones estratégicas, uso interno, para el consumidor. El ámbito de aplicación o alcance de un ACV tendrá en cuenta el producto a ser estudiado, la función del producto, la unidad funcional, los límites del sistema, los procedimientos de asignación de cargas (Kg, €, h, otros…), categorías y metodología de análisis de impacto seleccionados, requerimiento de calidad de los datos, hipótesis y limitaciones del estudio, tipo de revisión crítica, tipo y formato del estudio.

La unidad funcional es la unidad a la que hace referencia todo el estudio, un ejemplo del estudio de ACV de un edificio sería "Construcción, uso durante 80 años y fin de vida de un edificio de PB+5PP en Girona (zona climática C2)."

Los límites del análisis determinarán todos procesos para la obtención del producto, de la cuna a la tumba, a incluir en el inventario.

El análisis del inventario consiste en el análisis de datos por cada unidad de proceso establecido en el ciclo de vida que se evalúa, teniendo en cuenta todas las entradas y salidas de los indicadores de cada categoría de impacto. Estos datos se pueden clasificar en diferentes grupos, el primero podría ser entradas de energía, materias primas, aditivos, y otras entradas físicas. El segundo, productos, coproductos y residuos. Tercero emisiones al aire, descargas al suelo y al agua. Cuarto otros aspectos ambientales, figura 2.3.

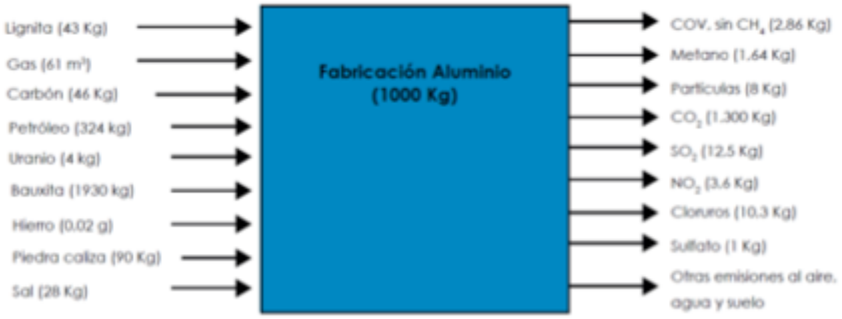


Figura 2.3: Análisis de inventario para la fabricación de un Kg de aluminio. Fuente: Comunidad de Madrid.

Una vez hemos realizado el inventario y hemos determinado las cantidades de materia, energía, emisiones etc. pasamos a la siguiente fase el Análisis del impacto del ciclo de vida donde pasamos los datos del inventario con los daños causados por dichas sustancias, mediante el uso de factores de caracterización. Ejemplo: Obtención de CO2 eq.=Calentamiento Global (Midpoint category)=Climate Change (Life support System).

La interpretación de los resultados corresponde en concreto a la evaluación del impacto ambiental en relación con el objetivo y al alcance del estudio con el fin de obtener conclusiones y recomendaciones. La interpretación de los resultados nos permite determinar aquellas etapas del ciclo de vida con mayor impacto, determinar aquellos procesos que consumen más recursos y generan más residuos y emisiones, determinar los contaminantes con mayor impacto y analizar el comportamiento de una sustancia en concreto.

Para llevarse a cabo un estudio ACV sobre un producto se hace imprescindible para que este análisis sea comparable con otros, la creación de unas reglas de categoría de producto o Product Category Rules por sus siglas en inglés (PCR). Las PCR son documentos específicos que definen las reglas bajo las cuales han de llevarse a cabo los estudios de ACV y la información que ha de mostrar una etiqueta medioambiental tipo III.

Cada PCR incluye una definición detallada de los productos que entran en el alcance, definición de la unidad funcional del estudio de ACV, los límites del sistema a analizar, los criterios de corte aceptados, detalles sobre la información a incluir y tener en cuenta en cada fase del ciclo de vida el producto. Selección de los tipos de datos a emplear, bases de datos compatibles y aceptadas para el estudio, clasificación de las categorías de impacto ambiental para mostrar los resultados del estudio, otro tipo de parámetros o escenarios (de uso, de fin de vida) a considerar en el estudio de ACV. Información ambiental que tiene que mostrar una etiqueta tipo III.

Las etiquetas tipo III son ecoetiquetas y se regulan mediante la norma ISO 14025 (Environmental labels and declarations. Type III environmental declarations. Principles). De esta tipología nacen las declaraciones ambientales de producto (EPD, Environmental Product Declarations) que son documentos que ofrecen de forma transparente y verificable por una tercera parte independiente, información relativa al comportamiento ambiental del producto o servicio certificado en base un estudio de ACV del mismo.

Es importante aclarar que en las EPD no se definen requisitos ambientales o valores mínimos a cumplir, sino que muestran los resultados del estudio de ACV llevado a cabo sobre el producto certificado para poder ofrecer una imagen de comportamiento ambiental del mismo, figura 2.4.

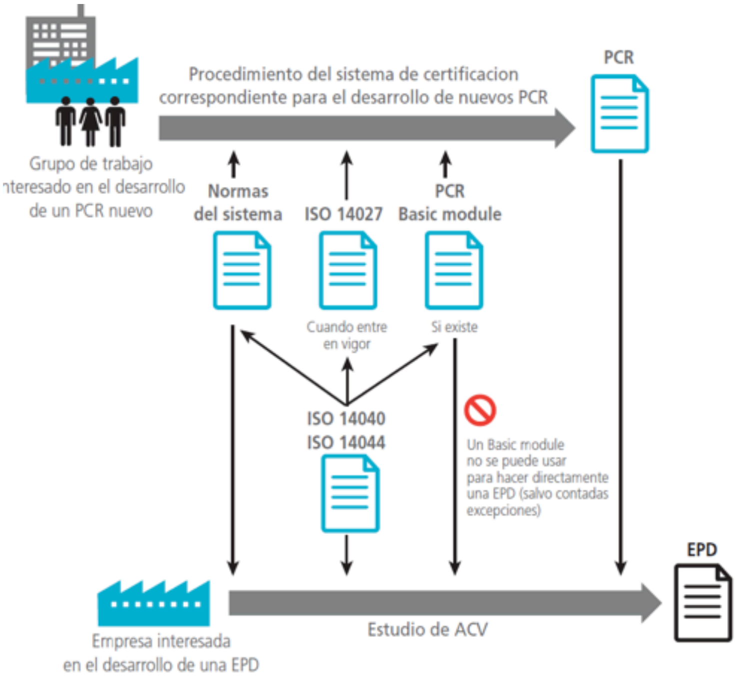


Figura 2.4: Relación entre referenciales y normas en el desarrollo de PCRs y EPDs. Fuente: ihobe.

El ACV es una metodología científica que permite determinar de forma objetiva y verificable los impactos sobre el medio ambiente, la economía y los impactos sociales.

2.1.3 ACV en el sector de la edificación

En el mercado actual existen diferentes tipos de etiquetado ecológico, tipo I (ecoetiquetas), tipo II (Auto-declaración) y tipo III (Declaración ambiental). La tipo I es un programa voluntario desarrollado por un tercero (ej: la Generalitat de Catalunya), que certifican de forma oficial que ciertos productos o servicios tienen un impacto menor sobre el Medio Ambiente. La tipo II es una auto-declaración realizada por los propios fabricantes, importadores, distribuidores etc. La tipo III es una declaración ambiental que se basa en el ACV y que proporciona datos ambientales cuantitativos y o cualitativos.

Las etiquetas ecológicas Tipo III verificadas por una tercera parte son la forma más rigurosa e internacionalmente aceptadas para la declaración de datos ambientales. Las diferentes certificaciones de sostenibilidad en la edificación como pueden ser; VERDE, LEED, BREEAM, DGNB las tienen muy en cuenta para la adjudicación de puntos en las categorías de materiales. Este etiquetado está basado en diferentes normas internacionales en base el ACV y en el sector de la construcción se basan en una serie de reglas, requerimientos y guías específicas, establecidas por producto o familia de productos, *figura 2.5.*

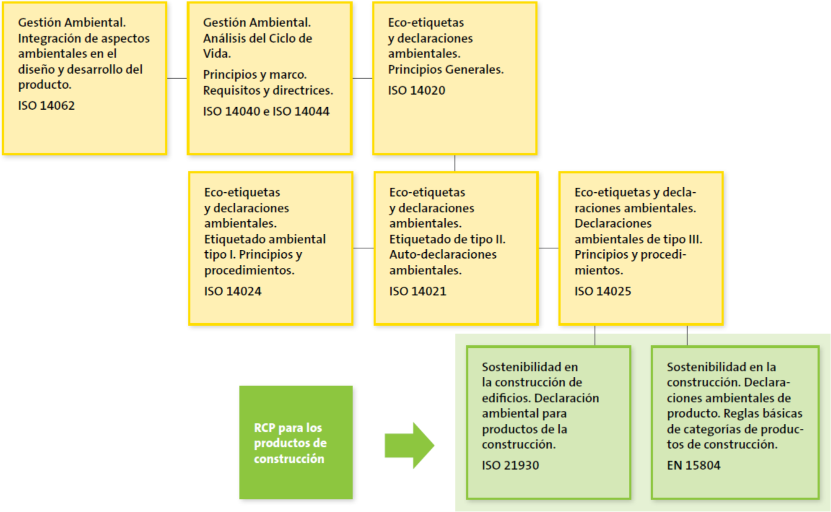


Figura 2.5: Normativa relativa a ecoetiquetas en productos de la construcción. Fuente: ISOVER 2013.

Cuando se realiza una DAP (Declaración ambiental de producto) o una EPD (Environmental Product Declaration) siglas en inglés, existen dos tipos de categorización de producto el estándar internacional ISO 21930 y la norma Europea EN 15804.

La norma EN 15804 define los parámetros que se deben declarar y la forma en que se reportan, describe que fases del ciclo de vida del producto que se consideran en las DAP y procesos que se incluyen, define las reglas para el desarrollo de escenarios, incluye las reglas de cálculo del inventario del ciclo de vida y del análisis del Ciclo de Vida señalados en la DAP, reglas para el reporte de información, y condiciones de comparación de los productos de construcción, figura 2.6.

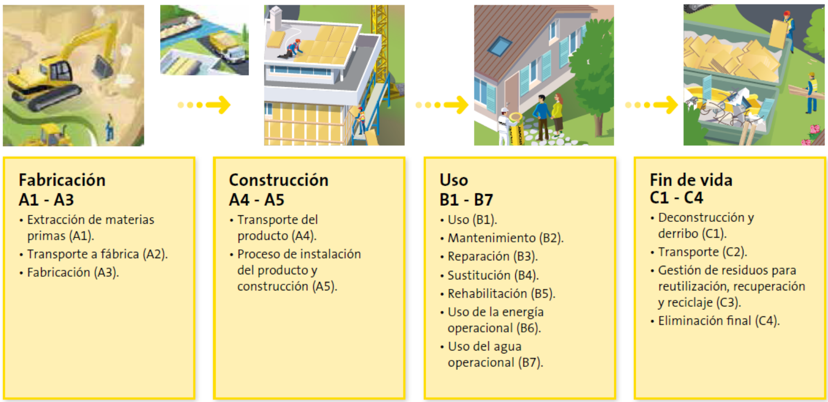
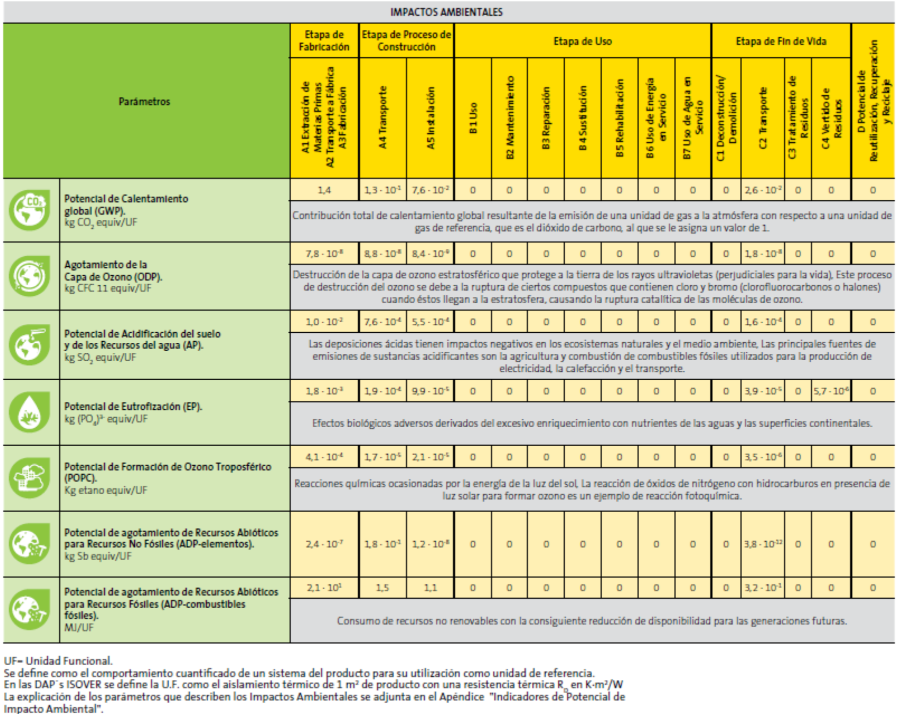


Figura 2.6 Etapas del análisis del ciclo de vida según EN 15804. Fuente: ISOVER 2013.

El estudio de ACV de un producto de la construcción deberá ir desde “la cuna a la tumba”. Este análisis empieza con la etapa de fabricación del producto, en la que las materias primas se extraen, se procesan, se seleccionan y finalmente se transportan a planta de fabricación del producto. En la fase de construcción los productos de construcción se transportan desde la planta de fabricación a los distribuidores y estos a la obra para ser instalados. Una vez instalado se inicia la etapa de uso en la que se incluye el mantenimiento, la reparación o sustitución de los productos instalados. En la etapa fina de la vida útil, el edificio es demolido y sus componentes se procesan para su reutilización, recuperación, reciclaje o disposición final como residuo. Más allá de estas etapas existe un módulo D, que proporciona información sobre el potencial de reutilización, de recuperación y/o reciclaje, tabla 2.1.



IMPACTOS AMBIENTALES															
Parámetros	Etapa de Fabricación	Etapa de Proceso de Construcción		Etapa de Uso							Etapa de Fin de Vida				D Potencial de Reutilización, Recuperación y Reciclaje
	A1 Extracción de Materias Primas A2 Transporte a Fábrica A3 Fabricación	A4 Transporte	A5 Instalación	B1 Uso	B2 Mantenimiento	B3 Reparación	B4 Sustitución	B5 Rehabilitación	B6 Uso de Energía en Servicio	B7 Uso de Agua en Servicio	C1 Deconstrucción/ Demolición	C2 Transporte	C3 Tratamiento de Residuos	C4 Vertido de Residuos	
Potencial de Calentamiento global (GWP). kg CO_2 equiv/UF	1,4	$1,3 \cdot 10^{-1}$	$7,6 \cdot 10^{-2}$	0	0	0	0	0	0	0	0	$2,6 \cdot 10^{-2}$	0	0	0
	Contribución total de calentamiento global resultante de la emisión de una unidad de gas a la atmósfera con respecto a una unidad de gas de referencia, que es el dióxido de carbono, al que se le asigna un valor de 1.														
Agotamiento de la Capa de Ozono (ODP). kg CFC 11 equiv/UF	$7,8 \cdot 10^{-8}$	$8,8 \cdot 10^{-8}$	$8,4 \cdot 10^{-9}$	0	0	0	0	0	0	0	0	$1,8 \cdot 10^{-8}$	0	0	0
	Destrucción de la capa de ozono estratosférico que protege a la tierra de los rayos ultravioletas (perjudiciales para la vida). Este proceso de destrucción del ozono se debe a la ruptura de ciertos compuestos que contienen cloro y bromo (clorofluorocarbonos o halones) cuando éstos llegan a la estratosfera, causando la ruptura catalítica de las moléculas de ozono.														
Potencial de Acidificación del suelo y de los Recursos del agua (AP). kg SO_2 equiv/UF	$1,0 \cdot 10^{-2}$	$7,6 \cdot 10^{-4}$	$5,5 \cdot 10^{-4}$	0	0	0	0	0	0	0	0	$1,6 \cdot 10^{-4}$	0	0	0
	Las deposiciones ácidas tienen impactos negativos en los ecosistemas naturales y el medio ambiente. Las principales fuentes de emisiones de sustancias acidificantes son la agricultura y combustión de combustibles fósiles utilizados para la producción de electricidad, la calefacción y el transporte.														
Potencial de Eutrofización (EP). kg $(PO_4)^{3-}$ equiv/UF	$1,8 \cdot 10^{-3}$	$1,9 \cdot 10^{-4}$	$9,9 \cdot 10^{-5}$	0	0	0	0	0	0	0	0	$3,9 \cdot 10^{-5}$	0	$5,7 \cdot 10^{-6}$	0
	Efectos biológicos adversos derivados del excesivo enriquecimiento con nutrientes de las aguas y las superficies continentales.														
Potencial de Formación de Ozono Troposférico (POPC). Kg etano equiv/UF	$4,1 \cdot 10^{-4}$	$1,7 \cdot 10^{-5}$	$2,1 \cdot 10^{-5}$	0	0	0	0	0	0	0	0	$3,5 \cdot 10^{-6}$	0	0	0
	Reacciones químicas ocasionadas por la energía de la luz del sol. La reacción de óxidos de nitrógeno con hidrocarburos en presencia de luz solar para formar ozono es un ejemplo de reacción fotoquímica.														
Potencial de agotamiento de Recursos Abióticos para Recursos No Fósiles (ADP-elementos). kg Sb equiv/UF	$2,4 \cdot 10^{-7}$	$1,8 \cdot 10^{-1}$	$1,2 \cdot 10^{-8}$	0	0	0	0	0	0	0	0	$3,8 \cdot 10^{-12}$	0	0	0
Potencial de agotamiento de Recursos Abióticos para Recursos Fósiles (ADP-combustibles fósiles). MJ/UF	$2,1 \cdot 10^{1}$	1,5	1,1	0	0	0	0	0	0	0	0	$3,2 \cdot 10^{-1}$	0	0	0
	Consumo de recursos no renovables con la consiguiente reducción de disponibilidad para las generaciones futuras.														

UF= Unidad Funcional.
Se define como el comportamiento cuantificado de un sistema del producto para su utilización como unidad de referencia.
En las DAP´s ISOVER se define la U.F. como el aislamiento térmico de 1 m² de producto con una resistencia térmica R_D en K·m²/W
La explicación de los parámetros que describen los Impactos Ambientales se adjunta en el Apéndice "Indicadores de Potencial de Impacto Ambiental".

Tabla 2.1: Tabla ide mpactos ambientales para 1 m2 de lana mineral de resistencia térmica (R): 1,4 k.m2.w-1. Fuente: ISOVER 2013.

En el caso de un edificio la forma más adecuada y reconocida de llevar a cabo un análisis medioambiental de un edificio, es mediante un estudio de ACV del mismo y para esto es fundamental disponer de las correspondientes ecoetiquetas tipo III, verificadas por una tercera parte.

Sobre la aplicación ACV en la edificación, Verbeeck et al. (2010), nos confirman que la energía embebida de un edifico es relativamente poco importante comparado con la energía consumida en fase de uso de la vivienda y el retorno es en menos de dos años. Evidentemente esto estará en función de lo energéticamente eficiente que sea el edificio construido. Como ejemplo de la utilización del ACV, Wang et al. (2010), utilizan esta metodología para la toma de decisiones tanto ambientales como económicas en el diseño de un edificio comercial en Shanghai. Mithraratne et al. (2004), utilizan la metodología del ACV como herramienta para el diseño de casas en Nueva Zelanda basadas en el cálculo de la energía embebida y la energía consumida en la fase de uso y el análisis sobre las mismas mediante el análisis de los costes del ciclo de Vida (CCV).

2.2 La Evaluación de la Eficiencia Energética

2.2.1 La Eficiencia energética en la Unión Europea (UE)

La UE ha desarrollado diferentes Directivas sobre eficiencia energética (EPBD) con el objetivo de reducir el consumo energético un 20%, que un 20% de la energía generada sea de fuentes renovables y la reducción de los gases de efecto invernadero un 20% respecto el 1990 todo para el año 2020. Esto a llevado a los estados miembros de la unión en virtud de sus correspondientes transposiciones de la normativa, a desarrollar diferentes sistemas para la evaluación de la eficiencia energética en edificios mediante la realización de certificados energéticos (EPC).

Estas diferencias han comportado que existan diferentes escalas para medir la eficiencia energética y a la vez que algunos países no incluyan una escala de emisiones de CO2.

Estudios realizados por la Unión Europea, indicaban que las viviendas y el sector servicios eran los responsables del 16% de las emisiones de CO2eq y la hoja de ruta para el 2050, tiene como objetivos que en el 2030 la reducción de estas emisiones en un 37%-53% y para el 2050 en un 88%-91%.

La UE en el 2009 adoptó una serie de medidas legislativas sobre energía y el cambio climático denominado “Paquete legislativo sobre energía y clima” (climate and energy package) con el objetivo de la reducción de un 20% de las emisiones de gases de efecto invernadero para el 2020 en base las emisiones del 1990 en virtud del Protocolo de Kyoto.

Según la Directiva 2010/31/UE relativa a la eficiencia energética de los edificios, el 40% del consumo total de energía final en la UE corresponde a los edificios, una de las medidas que propone es la reducción del consumo energético en un 20%, a la vez que establece que como máximo a partir del 31 de diciembre de 2020, todos los edificios nuevos serán edificios de consumo energético casi nulo y que a partir del 31 de diciembre de 2018, los edificios nuevos ocupados que sean propiedad de autoridades públicas dedeberán poder califificarse de consumo de energía casi nulo (nzeb).

Con el objetivo de desarrollar una metodología de cálculo de eficiencia energética, la UE en el anexo de la directiva 2002/91/EC y posteriormente en la Directiva 2010/31/UE estableció directrices que definen el marco legal para el cálculo de la eficiencia energética en los edificios. Esta directiva, juntamente con las normativas de desarrollo propias de cada país tiene como objetivo establecer el consumo térmico en la fase de uso o operacional en viviendas. La cetificación energética principalmente promueve la mejora de la eficiencia energética en edificios en base una clasificación energética (energy labelling).

Estas metodologías no tienen en cuenta el estudio ACV, con lo cual no tienen en cuenta la energía embebida (embodied energy) propia de la fabricación de los materiales. Esto puede llegar a provocar que un edificio con una elevada energía embebida y muy eficiente, tenga un certificado energético elevado, y un edificio construido con materiales de baja energía embebida y un consumo elevado tenga un certificado energético malo. Pero si tuviéramos en cuenta los dos parámetros durante una vida útil estimada, se podría dar el caso que el segundo edificio fuera más eficiente que el primero en términos totales de energía consumida.

Todas estas normativas se focalizan en la eficiencia energética con el objetivo de reducir los consumos y la dependencia energética del exterior, pero no se tiene que olvidar que este factor tiene un impacto directo en las emisiones de CO2. Se tiene que tener en cuenta que no todos los países tienen las mismas políticas energéticas y esto influye directamente en las emisiones de CO2. Este factor recibe el nombre de carbonatación o intensidad de carbono de la energía, definida como el CO2 emitido por unidad de energía consumida. Otro factor importante es el de la intensidad energética que nos sirve de indicador para medir la eficiencia energética, definida como energía consumida por unidad de PIB.

Los primeros en implantar medidas para cumplir las directrices de la UE serán los edificios públicos, un ejemplo es el descrito por Mata et al., 2009 en edificios de la Universidad Politécnica de Cataluña.

Es evidente que los países dependientes de energías fósiles contaminan más que los que tienen un alto grado de energías renovables, pero no es tan evidente que estos países sean los más contaminantes cuando se compara en función de la intensidad energética, la renta económica y la población, tabla 2.2.

	Kaya identity factors						
	CO2	Carbonation index CO2/E	Energy Intensity E/GDP	GDP per capita GDP/P	Population P	Emission intensity of GDP CO2/GDP	Emissions per capita CO2/P
Austria	66.63	2.17	154.32	24.49	8.13	334.71	8.20
Belgium	119.6	2.03	230.42	24.91	10.28	467.10	11.63
Denmark	50.45	2.55	143.25	25.76	5.36	365.37	9.41
Finland	60.23	1.78	271.21	24.03	5.19	483.00	11.61
France	384.85	1.45	190.44	22.89	60.91	275.97	6.32
Germany	850.16	2.42	182.67	23.34	82.34	442.32	10.32
Greece	90.15	3.14	173.70	15.08	10.96	545.60	8.23
Ireland	43.11	2.88	136.08	28.59	3.85	391.62	11.20
Italy	425.27	2.47	133.60	22.22	57.93	330.33	7.34
Luxemburg	8.41	2.20	199.27	43.68	0.44	437.57	19.11
The Netherlands	177.48	2.30	193.48	24.88	16.04	444.76	11.06
Portugal	59.05	2.39	148.31	16.58	10.06	354.12	5.87
Spain	285.6	2.24	172.25	18.36	40.27	386.21	7.09
Sweden	48.05	0.94	236.84	24.22	8.9	222.92	5.40
United Kingdom	540.84	2.3	181.80	22.00	58.79	418.13	9.2
European Union	3,209.88	2.15	177.33	22.22	379.44	380.74	8.46
Coefficient of variation x 100		23.29	20.82	15.56		20.43	34.65

Tabla 2.2: Descomposición de las emisiones Europeas. Fuente: Alcántara et al, 2005.

La evolución de la eficiencia energética en Europa, ha ido determinada en un primer estadio por el desarrollo individual de algunos estados miembros de medidas de ahorro energético y su comunicación en base de etiquetas de eficiencia energética, para ser adoptadas más tarde con las correspondientes adaptaciones a las directivas Europeas.

El primer país en introducir un sistema de cálculo para medir los ratios de energía en edificios de viviendas, fue el Reino Unido, que en 1995 estableció unos "energy ratings" utilizando el ·Standard Assessment Procedure (SAP, este sistema fue evolucionando, hasta el actual sistema del año 2005. El primer país en utilizar un "energy labelling schemes" fue Dinamarca en 1997 a la vez que creó una base de datos centralizada que sirvió como modelo para la creación de las EPBD.

El 15 de enero de 1985 la Comunidad Económica Europea (CEE) anima a los estados miembros a seguir con las políticas de ahorro energético, en base a esto el 29 de Octubre de 1991 se aprueba la decisión 91/565/CEE en la que se aprueba el programa SAVE (acciones específicas para una mayor eficacia energética) embrión de las futuras políticas de eficiencia energética de la Unión Europea. El 13 de setiembre de 1993 se aprueba la Directiva 93/76/CEE relativa a la limitación de las emisiones de dióxido de carbono mediante la mejora de la eficiencia energética, siendo uno de los primeros documentos donde se mencionan de forma clara las políticas de estabilización y reducción de las emisiones de CO2, juntamente con la afirmación que el sector de la vivienda y de edificios terciarios absorben el 40% del consumo final de energía de la Comisión Europea (CE) UE y que están en expansión. También tiene por objetivo la limitación, por parte de los estados miembros, de las emisiones de CO2, mediante la mejora de la eficiencia energética en el sector público mediante el aislamiento térmico de los edificios nuevos, la inspección periódica de calderas y auditorias energéticas de las empresas de elevado consumo energético, figura 2.7.

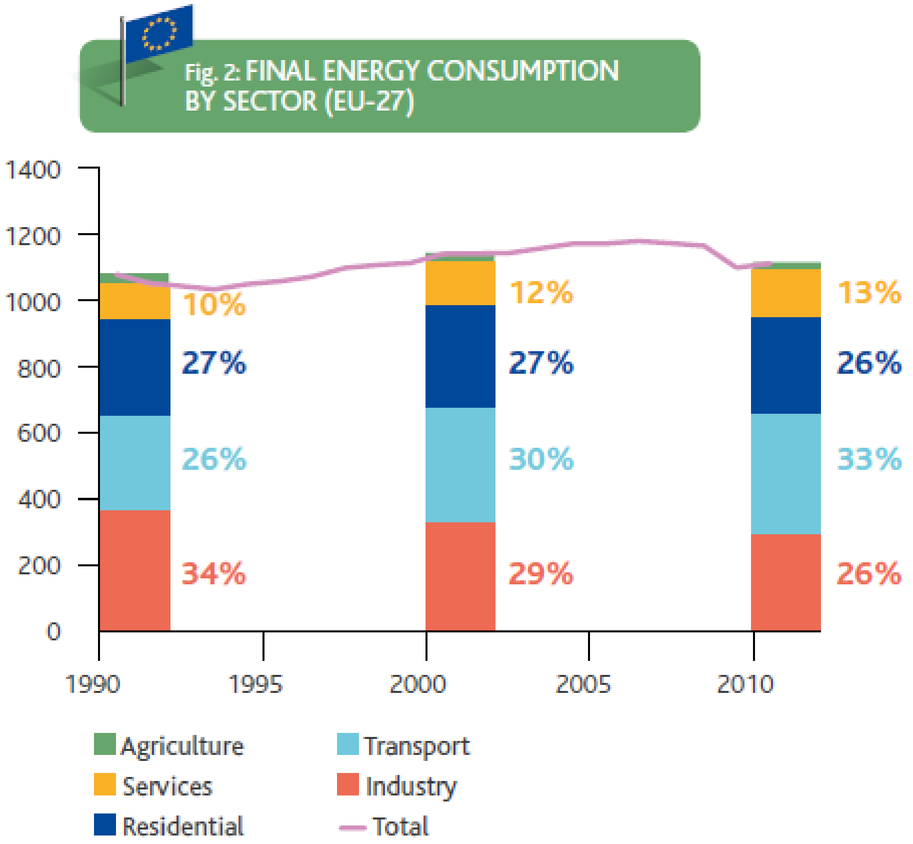


Figura 2.7: Consumo de energía final por sector (EU-27). Fuente: Odysee.

El 29 de noviembre de 2000 la CE adoptó como propio el documento “Green Paper: Towards a European Startegy for the security of Enery Suplly”. En este informe se realiza un análisis del estado actual de Europa en temas energéticos y su elevada dependencia de otros países, juntamente con un elevado consumo de energía fósil con las consecuencias emisiones generadas y por tanto la aplicación de Kyoto. El documento también hace referencia a las actuaciones a realizar delante de este problema y una de las propuestas es la mejora de la eficiencia energética en diferentes sectores, particularmente el de la edificación, figura 2.8.

El 16 de diciembre de 2002 la CE adoptó la primera directiva 2002/91/UE que de una manera clara establecía que la eficiencia energética de los edificios tenía que ser calculada con una metodología que podía ser diferente a escala regional y que tenía que comprender no solo el aislamiento, si no también las instalaciones de calefacción y aire acondicionado, la utilización de fuentes de energía renovables y el diseño del edificio. Al mismo tiempo establecía que los edificios nuevos tenían que cumplir unos requisitos mínimos de eficiencia energética adaptados a las condiciones climáticas locales. A nivel económico establece que las medidas de eficiencia energética a realizar tendrán un retorno razonable de la inversión en función de su vida útil. A nivel de comunicación la eficiencia energética de un edificio se expresará de una forma clara y podrá incluir un indicador de emisiones de CO2. Este aspecto es importante ya que la comunicación de CO2 no es obligatoria.

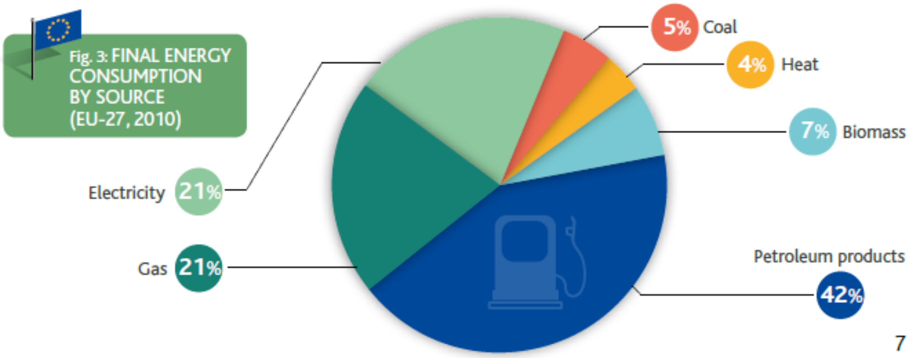


Figura 2.8: Consumo de energía final por recurso (EU-27,2010). Fuente: Odysee.

La Directiva 2010/31/UE de l 19 de mayo de 2010 relativa a la eficiencia energética de los edificios es la refundición de todas EPBD existentes. Esta normativa es conocida coloquialmente como la 20/20/20 que pretende como objetivo reducir para el 2020 las emisiones de los gases de efecto invernadero en un 20%, la reducción del consumo energético en un 20% y que las energías de fuentes renovables sean de un 20%. Los requisitos establecidos son:

- Una metodología de cálculo de la eficiencia energética de los edificios o unidades de edificios.
- La aplicación de requisitos mínimos a la eficiencia energética de los edificios nuevos, existentes, reformas del envolvente, instalaciones técnicas.
- El aumento de edificios de consumo de energía casi nulo.
- Certificación energética de edificios e informes de inspección.
- Sistemas de control independiente de los certificados de eficiencia energética.

En la actualidad a parte de la directiva 2010/31/UE hay diferentes Directivas, Reglamentos y directrices que ayudan al objetivo propuesto anteriormente. Algunas de estas normativas son la Directiva 2012/27/UE de 25 de Octubre de 2012, relativa a la eficiencia energética, el Reglamento Delegado (UE) 244/2012 del 16 de enero de 2012, y las Directrices 2012/C115/01 que acompañan el reglamento anterior.

La discusión actual de la UE son los objetivos para el 2030 de un 40% de las emisiones de CO2 de forma obligatoria, el 27% de energía de fuentes renovables a nivel Europeo sin ser vinculante para los estados y elevar el 30% la eficiencia energética, figura 2.9.

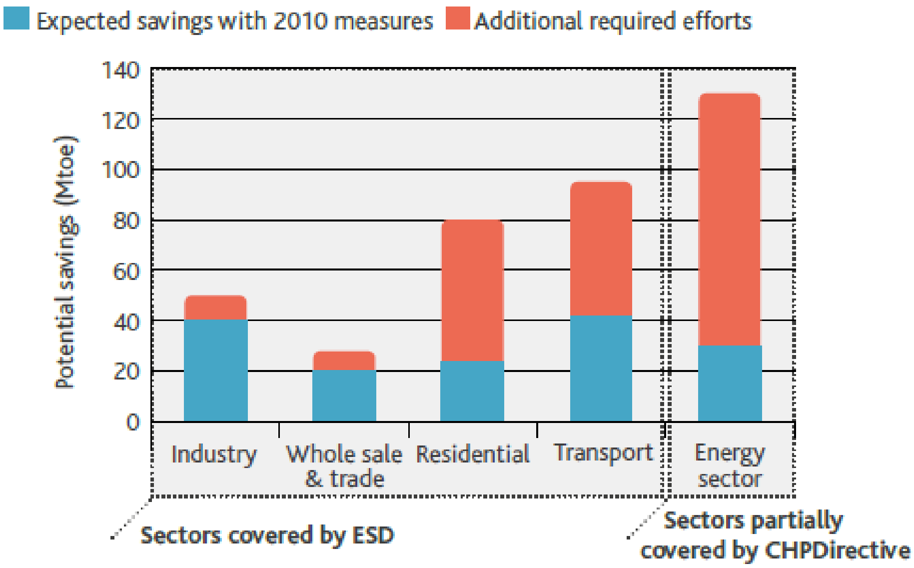


Figura 2.9: Gráfico de los energéticos esperados esperados hasta el 2010 y de los recursos adicionales a realizar para alcanzar los objetivos propuestos. Fuente: DEE-Impact Assessment (SEC/2011/779).

2.2.2 Los Certificados Energéticos en Europa (EPC)

Dascaki EG et al. (2013), en su artículo nos ofrece un estado de la cuestión sobre las EPCs (Energy Performance Certificates) en los diferentes estados de EU hasta mediados del año 2013, donde se hace mención de la disparidad de la aplicación de la normativa debido al retraso de la transposición de la EPBD.

Uno de los otros problemas surgidos es la disparidad de registros de los diferentes estados miembros de la UE. Algunos tienen registros centralizados a nivel nacional, otros a nivel regional y otros no tinen ningún registro. Esto provoca que el número de certificados realizados entre los diferentes países esté entre un 1% y un 24%. El porcentage de viviendas pendientes de la EPC, es entre el 80%-90%.

Esta problemática afecta directamente a uno de los objetivos de la directiva que era la realización de un “benchmarking” comparativo entre paises. Esto agravado por la disparidad de datos contemplados en los diferentes EPC de los estados miembros.

Si que es cierto que desde un punto de vista de la gestión de la información proporcionada por los EPCs, permite a los estados y regiones de forma interna, la realización de estudios y la aplicación de políticas de mejora de eficiencia energética.

El EPC es un documento muy importante e indispensable, porqué tiene que informar a los potenciales compradores, arrendadores y usuarios sobre la eficiencia energética de los edificios o unidades de edificios (piso u oficina), y permitir comparar unidades de edificios o edificios en su totalidad. Uno de los objetivos de la creación de las EPCs, es promocionar la demanda de edificios o unidades de edificios más eficientes energéticamente. Es por esto que la información de la etiqueta es muy importante, ya que dependen de los tipos de indicadores y del diseño influenciará en la información que se da y se publicita.
Básicamente el diseño de las etiquetas energéticas y los certificados de eficiencia energética se tienen que basar en la normativa EN 15217 donde se define, formatos de etiqueta, procedimiento para la clasificación, procedimiento para la documentación de la certificación, procedimiento para la certificación, valores de referencia, indicadores de eficiencia, símbolos y abreviaturas.

Es importante tener en cuenta que un EPC, básicamente está formado por dos partes, el EPC propiamente, que es un documento de 3-5 páginas en función del país, y por otra parte la etiqueta energética (Energy performance label), que es un documento de una hoja, donde se muestra de manera resumida los datos más importantes.

Uno de los problemas en los que nos encontramos al comparar los niveles de eficiencia energética y de CO2 es el simbolismo gráfico de representación. Hay paises que utilizan una escalera de clasificación y otras solo un indicador sin escala de clasificación. Hay 25 paises que utilizan una escala de clasificación y seis que utilizan un indicador sin clasificación.

Si se comparan entre ellos mismos por grupos, según el formato de representación, también encontramos diferencias. Por ejemplo en el caso de las escalas de clasificación tenemos diez países que utilizan una escala de la (A-G), siendo la A la más eficiente, y la G menos eficiente. Después hay tres países que utilizan una escala de la (A++,A+,…G), cinco países que utilizan la escala (A+,A,…G), dos que utilizan (A+,A, B+, B, C…G) y el conjunto restante de países que utilizan sus propias escalas de clasificación.

En cuanto a las unidades de cálculos se puede comprobar que la mayoría utilizan los Kwh/m2.yr de energía primaria, pero todo y utilizar la misma unidad, no son comparables, ya que se han calculado de forma diferente, debido al factor de conversión de energía final a energía primaria o viceversa, ya que este factor depende de la infraestructura de este país.

En el caso de las emisiones se puede comprobar que tienen simbolismo gráfico once países. En cuanto a la información cuantitativa de las emisiones 18 países informan de las mismas, pero cabe tener en cuenta que algunos como Francia, Portugal e Inglaterra miden CO2eq y los otros CO2.

Tal como se ha podido comprobar se hace imposible la comparación entre países de forma general, ya que otros factores, como pueden ser: el concepto de m2 útil, el mix energético como factor de conversión de energía a emisiones de CO2, la propia metodología de cálculo, etc., complican esta comparación.

2.2.3 La Eficiencia Energética de edificios en España (EPBD) y los Certificados Energéticos(EPC)

En el año 2007 se publicó el RD 47/2007, de 19 de enero por el que se aprobaba el procedimiento básico para la certificación energética de edificios de nueva construcción. Este decreto establecía la obligatoriedad de que todos los edificios que se construyan nuevos, dispongan de la calificación de eficiencia energética.

El año 2013 se publicó el RD 235/2013, de 5 de abril, por el que se aprobaba el procedimiento básico para la certificación de la eficiencia energética de los edificios, tanto nuevos, como existentes, este Real Decreto establece que cualquier edificio (con algunas excepciones) o parte del mismo que se alquile o venda tendrá que obtener el certificado de eficiencia energética. Este Real decreto derogó y substituyó el RD 47/2007. Esta metodología es de aplicación en toda España pero las diferentes comunidades autónomas son las responsables de la realización de los trámites para la obtención del certificado energético, tabla 2.3.

Los objetivos principales son informar al comprador o arrendatario mediante una escala de la letra A a la G (A es más eficiente, y la G es menos eficiente), fomentar la construcción de edificios más eficientes e impulsar la rehabilitación del parque de edificios existentes.

El procedimiento genérico para la realización de la certificación energética de edificios consiste en:

a) Informe, documento generado mediante un procedimiento técnico de cálculo para determinar el comportamiento energético del edificio o parte del mismo y las posibles mejoras energéticas mediante las herramientas reconocidas por el Ministerio de Industria, Energía y Turismo del Gobierno de España.
b) Certificación, es el trámite administrativo por el que se valida el certificado y se inscribe en el registro de certificados de eficiencia energética de edificios de las diferentes comunidades autónomas de España.
c) Etiqueta energética, una vez revisada y validada la documentación presentada, el organismo competente de la Autonomía envía la etiqueta de eficiencia energética al propietario del edificio con una validez de 10 años.

La etiqueta energética da información sobre las emisiones de CO2 (KgCO2/m2.año) y de consumo de energía primaria (Kw.h/m2.año) del edificio o parte del mismo según nuestro estudio (un edificio, un piso, local…). Este ratio depende de la demanda y consumo de energía de varios sistemas como pueden ser la calefacción, el aire acondicionado, el agua caliente sanitaria y la luz para edificios de uso terciario. Hay diferentes herramientas de cálculo utilizados para obtener las emisiones y la energía primaria consumida.

	Opción Simplificada	*Opción General*
Edificios Nuevos	CES, C2, CERMA	CALENER VyP, CALENER GT
Edificios Existentes	CE3X, CE3	CALENER VyP, CALENER GT

Tabla 2.3: Herramientas de certificación de eficiencia energética en España. Fuente: Propia.

Actualmente en España existen 25.208.622 viviendas, aproximadamente el 55% de estas han sido construidas antes del año 1980 y casi el 21% tienen más de 50 años. Se puede comprobar en el informe generado en fecha 1 de junio de 2014 por el Ministerios de Industria, Energía y Turismo el número de certificados de eficiencia energética (EPC) realizados hasta el momento. Según estos datos se puede comprobar que solo 659.499 viviendas han estado certificadas, esto representa un 2,6% del parque edificatorio total, tabla 2.4.

	Date update	New	Existing
ANDALUCIA	31/03/2014	609	88,308
ARAGÓN	07/04/2014		32
ASTURIAS	01/04/2014	17	3,993
BALEARES	23/04/2014	188	18,017
CANARIAS	11/11/2013	181	32,172
CATALUNYA	01/04/2014	5,53	195,089
C. LEÓN	24/04/2014	72	27,7
C. MANCHA	31/03/2014	17	10,507
EXTREMADURA	17/01/2014	3,015	1,072
GALICIA	31/03/2014	65	399
MURCIA	10/04/2014	154	16,233
NAVARRA	31/12/2013	747	5,926
PAIS VASCO	27/05/2014	125	17,085
RIOJA	31/03/2014	283	5,388
VALENCIA	03/04/2014	2,951	128,888
MADRID	01/04/2014	176	91,368
CANTABRIA	08/05/2014	10	3,182
TOTAL		**14,140**	**645,359**

Tabla 2.4: Certificados Eficiencia Energética por comunidades Autónomas. Fuente: Ministerio de Industria, turismo y energía de España.

En la tabla 2.5 y en la figura 2.11 se puede comprobar el nivel de clasificación en función de las emisiones de CO2 por comunidades autónomas como por número de certificados realizados en edificios nuevos. De estos datos se extrae que un 39% de los certificados emitidos corresponden a la clasificación de las letras E,F y G.

	A	B	C	D	E	F	G	
ANDALUCIA	15	43	122	337	73	8	11	609
ARAGÓN	0	0	0	0	0	0	0	
ASTURIAS	0	4	5	1	7	0	0	17
BALEARES	1	4	6	28	63	31	55	188
CANARIAS	1	4	12	42	55	16	51	181
CATALUNYA	526	823	988	1903	1,29	0	0	5,53
C. LEÓN	20	9	13	18	11	1	0	72
C. MANCHA	2	3	8	3	1	0	0	17
EXTREMADURA	24	87	211	560	2,133	0	0	3,015
GALICIA	12	13	10	15	15	0	0	65
MURCIA	0	1	4	26	77	25	21	154
NAVARRA	114	140	137	179	136	20	21	747
PAIS VASCO	3	7	50	57	7	1	0	125
RIOJA	1	10	29	93	120	16	14	283
VALENCIA	8	11	69	1,598	1,265	0	0	2,951
MADRID	2	37	79	36	18	0	4	176
CANTABRIA	0	0	1	1	4	4	0	10
TOTALS	729	**1,196**	**1,744**	**4,897**	**5,275**	**122**	**177**	**14,140**

Tabla 2.5: Certificados Eficiencia Energética por comunidades Autónomas. Fuente: Ministerio de Industria, turismo y energía de España.

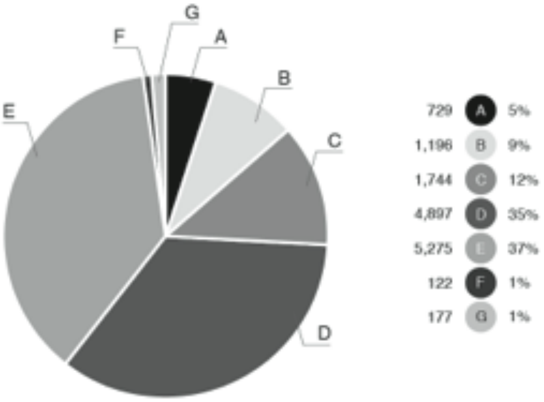


Figura 2.10: Clasificación de los edificios nuevos en función de las emisiones de CO2. Fuente: Ministerio de Industria, turismo y energía de España.

En la tabla 2.6 y la figura 2.12 se puede comprobar el nivel de clasificación en función de las emisiones de CO2 por comunidades autónomas como por el número de certificados realizados en edificios existentes. De estos datos se puede extraer que un 85% de los certificados corresponden a letras E,F,G.

	A	B	C	D	E	F	G	
ANDALUCIA	98	525	2,481	7,484	41,222	12,345	24,153	88,308
ARAGÓN	0	0	2	8	17	3	2	32
ASTURIAS	7	30	164	647	1,695	466	984	3,993
BALEARES	36	119	507	1,414	6,412	2,216	7,313	18,017
CANARIAS	70	294	957	966	2,999	2,979	23,907	32,172
CATALUNYA	280	1,366	8,123	22,892	86,985	26,259	49,184	195,089
C. LEÓN	205	202	1,738	5,542	13,903	2,405	3,705	27,700
C. MANCHA	17	35	295	1,812	5,487	1,043	1,818	10,507
EXTREMADURA	0	4	50	121	565	151	181	1,072
GALICIA	1	4	19	43	161	48	123	399
MURCIA	8	21	273	828	6,726	2,727	5,65	16,233
NAVARRA	14	68	418	1,424	2,526	660	816	5,926
PAIS VASCO	NO INFORMATION							
RIOJA	15	32	259	1,040	3,254	398	390	5,388
VALENCIA	54	1,19	2,131	8,27	61,813	16,262	39,168	128,888
MADRID	155	675	3,942	13,702	46,306	10,729	15,859	91,368
CANTABRIA	19	11	148	564	1,493	365	472	3,072
TOTALS	979	**4,576**	**21,507**	**66,757**	**281,564**	**79,056**	**173,725**	**628,164**

Tabla 2.6: Certificados Eficiencia Energética por comunidades Autónomas. Fuente: Ministerio de Industria, turismo y energía de España.

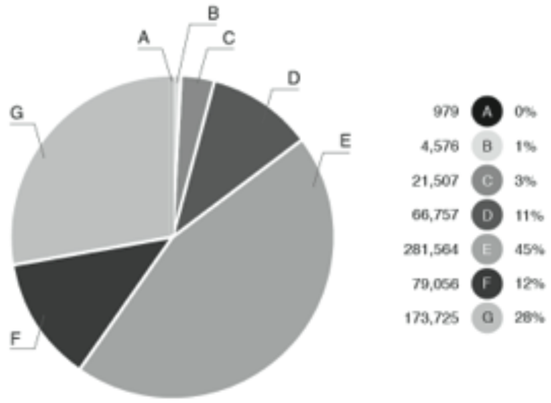


Figura 2.11: Clasificación de los edificios nuevos en función de las emisiones de CO2. Fuente: Ministerio de Industria, turismo y energía de España.

2.3 Herramientas para la evaluación de sostenibilidad de Edificios

2.3.1 Introducción a las herramientas de sostenibilidad

A partir de 1990 empezaron a aparecer diferentes herramientas para valorar los impactos medio ambientales de los edificios. En la actualidad las diferentes asociaciones de construcción sostenible a nivel de cada país, utilizan las herramientas que consideran más correctas para valorar los impactos medioambientales de los edificios. Las más conocidas son BEAM plus (Hong Kong) BREEAM (UK), CASBEE (Japan), DGNB(German), LEED(EEUU) y VERDE (España).

Building Research Establishment Environmental Assessment Method (BREEAM) fué según Grave M. (2000), y Prior J. (1993) la primera herramienta de evaluación medio ambiental de edificios que se desarrolló en UK durante 1990. BREEAM también fué adoptada como modelo de referencia por metodologías desarrolladas en Canadá, Nueva Zelanda, Noruega, Singapur, y Hong Kong. La siguiente metodología se desarrolló en Hong Kong en diciembre del año 1996, mediante una herramienta nombrada como HK-BEAM. A continuación la siguiente herramienta que se desarrolló fue “Leadership in Energy and Environment Design” (LEED), desarrollada por el US Green Building Council (USGBC) a demanda del US Department of Energy. La versión piloto se creó en agosto de 1998 y a partir de aquí se han ido desarrollando versiones hasta llegar a la actual v4. Comprehensive Assessment System for Built Environment Efficiency (CASBEE) es la metodología y herramienta de evaluación ambiental de edificios desarrollada en Japón y administarda por IBEC (“Institute for building Environment and Energy Conservation”), que fué introducida en el mercado el 2002. En el año 2007 se introdujo en el mercado el “Deutsche Gesellschaft für Nachhalties Bauen” (DGNB) herramienta de verificación de la edificación ambiental, desarrollada por el German Sustainable Building Council con el objetivo de ser un sistema internacional y de referencia Europeo ya que se basa en la normativa tecnológica con estándares Europeos.

En el estado Español la asociación de referencia sobre edificación sostenible es el Green Building Council España (GBCe) que fue reconocida como Established Council el año 2011. Esta asociación desarrolló la herramienta VERDE que tiene como característica principal el estudio de los impactos ambientales generados por los diferentes criterios analizados.

Estas herramientas han servido principalmente para establecer criterios y parámetros para que los diseñadores de edificios pudieran proyectar edificios sostenibles y los Promotores e Inversores los pudieran construir, figura 2.13.

Las dos herramientas de certificación ambiental de edificios más utilizadas a nivel internacional son la certificación BREEAM y LEED. Todas estas certificaciones han evolucionado con los años incorporando nuevas modificaciones y elevando el nivel de exigencia a medida que también evoluciona el desarrollo tecnológico. Un ejemplo claro puede ser la nueva versión del LEED donde incorpora créditos en el apartado de materiales y recursos y donde se valoran los materiales utilizados en el edifico que hayan hecho y certificado un estudio de Análisis y Ciclo de Vida. Otro ejemplo es la incorporación de créditos en acústica que anteriormente no incorporaba.

Figura 2.12: Imágenes de las diferentes certificaciones de sostenibilidad

Lee (2013) en su trabajo sobre herramientas de certificaciones en sostenibilidad donde contiene un estudio sobre BREEAM, LEED, CASBEE, BEAM plus y la China ESGB, nos indica la historia, metodologías usadas, estructura de las mismas, el alcance (tipología de edificios a certificar) y otors datos de utilidad.

Todd et al. (2001), hace referencia a la relación de los aspectos medioambientales, económicos y sociales, donde en un principio solo importaban los aspectos medioambientales para posteriormente ir incorporando los aspectos económicos y sociales, actualmente las certificaciones aún concentran su importancia en aspectos medioambientales.

Otro aspecto importante según Haapio et al. (2008), es la importancia de estas herramientas según la tipología de impacto. Para inversores, los aspectos económicos tendrán más importancia que los aspectos sociales y medioambientales, y los usuarios de una vivienda darán más importancia a la salud y confort del inmueble.

Schawartz et al. (2013), hacen una comparación entre diferentes herramientas de simulación energética en base un caso de estudio, y como afectan a la certificación BREEAM y LEED. El resultado obtenido es diferente en función de la herramienta de simulación energética, siendo las principales causas, el tratamiento que hacen las diferentes herramientas sobre la superficie del edificio y la caracterización de las temperaturas que utiliza cada herramienta para la realización de los cálculos, afectando finalmente a la demanda energética del edificio. La conclusión a que llegan es que en BREEAM se consiguen 6 de los 27 puntos y en el LEED no se llega al mínimo, y por tanto no se obtiene ningún punto, pero debido a la diferencia de importancia que tiene la categoría energía en ambas certificaciones el resultado final es invariable. Es importante resaltar las diferencias que hay entre las diferentes herramientas de simulación energética y el efecto que pueden tener en las diferentes certificaciones de sostenibilidad.

Una balanza más equilibrada en el peso de los impactos medioambientales, sociales y económicos es el aportado por la herramienta sBTool donde le corresponden un 40%, 30% y 30% respectivamente comparada por Ferreira et al. (2014) con las herramientas BREEAM y LEED.

Otra comparación entre la certificación BREEAM y LEED es la aportada por Seinre et al. (2014), donde hace un estudio sobre el peso de diferentes categorías de impacto como pueden ser “indoor climate quality, energy water use, material impact, project site” y los convierten en dos tipos de impacto ambientales y económicos, sugiriendo una nueva herramienta de evaluación para Estonia.

Muchas de estas certificaciones y concretamente el LEED y el BREEAM por su relevancia, aportan un estudio del ACV, de forma cualitativa. Pero por otro lado si se pretende un análisis de resultados cuantitativos el sistema de certificación tiene que ser diferente y se tiene que basar con el ACV en base las normas internacionales ISO 14044:2006 e ISO 14040:2006 que en el caso del sector de la edificación en Europa se complementan con las normas EN 15978 y EN 15804

Otras metodologías desarrolladas son MINERGIE y PASSIVHAUS pero estas están enfocadas únicamente a la reducción del consumo energético o edificios de consumo energético nulo o casi nulo (nZeb).

2.3.2 Criterios generales para la certificación BREEAM, DGNB, LEED, VERDE

La certificación BREEAM se estructura de diferentes formas en función de la tipología de edificio. En el caso de BREEAM ES viviendas se estructura en base a unas categorías de impacto y estas se subdividen en un número de requisitos, estos requisitos tienen una puntación, que la suma final determina la puntuación de la categoría, a su vez esta categoría tiene un peso ponderado en la certificación final. La suma de esta puntuación final nos indica el nivel de la certificación.

Las categorías de Impacto son: Gestión, Salud y Bienestar, Energía, Transporte, Agua, Materiales, Residuos, Uso del Suelo y Ecología, Contaminación y Puntos extraordinarios. A su vez estas categorías están formadas por unos requisitos, tabla 2.7.

GESTIÓN *• Puesta en servicio* *• Impacto en la zona de Obras* *• Guía de Usuario del Edificio*	*RESIDUOS* *• Gestión de residuos de la obra* *• Áridos Reciclados* *• Almacenamiento de residuos* *• Compostaje de residuos*
SALUD Y BIENESTAR • Iluminación natural • Aislamiento acústico • Iluminación artificial • Espacio privado de la vivienda • Viviendas adaptables	CONTAMINACIÓN • Uso y fugas de refrigerante • Riesgo de inundación • Emisiones de óxidos de nitrogeno • Contaminación de ciursos de agua • Reducción de la contaminación lumínica externa y contaminación acústica
ENERGÍA • Emisiones de CO2 • Tecnologías de cero o bajo carbono • Contadores auxiliares de energía • Sistemas de construcción energético-eficientes • Iluminación Interna	USO DEL SUELO Y ECOLOGÍA • Selección del emplazamiento • Protección de elementos de valor ecológico • Mitigación/mejora del valor ecológico • Huella del edificio
TRANSPORTE • Conectividad de la red de transporte público • Cercanía a servicios • Oficina en Casa	MATERIALES • Impacto de los materiales • Reutilización de los materiales • Aprovisionamiento Responsable de los materiales • Diseño orientado a la protección contra el impacto
AGUA • Consumo de agua • Detección de fugas importantes • Reutilización y reciclado del agua	INNOVACIÓN • Niveles ejemplares de eficiencia

Tabla 2.7: Categorías y requisitos según BREEAM ES Viviendas. Fuente: Guía BREEAM

La clasificación del esquema BREEAM ES vivienda para edificios nuevos y rehabilitaciones es la siguiente, tabla 2.8:

Clasificación BREEAM ES	*% puntuación*
SIN CLASIFICAR	<30
APROBADO	⩾30
BUENO	⩾45
MUY BUENO	⩾55
EXCELENTE	⩾70
EXCEPCIONAL	⩾85

Tabla 2.8: Niveles de clasificación según BREEAM ES Viviendas. Fuente: Guía BREEAM

En función de la puntuación y de la ponderación de las categorías nos determinarán el nivel de la certificación, es importante recordar que en función del nivel de certificación se tienen que cumplir unos requisitos mínimos. Para ver con claridad el proceso expondremos un ejemplo en la tabla 2.9.

CATEGORIAS	Puntos Conseguidos	*Puntos Disponibles*	*% Puntos Conseguidos*	*Ponderación Categoría*	*Puntuación por categoría*
Gestión	7	10	70%	11,5	8,05%
Salud y Bienestar	11	14	79%	14	11,00%
Energía	10	21	48%	18	8,57%
Transporte	5	10	50%	8	4,00%
Agua	4	6	67%	10,5	7%
Materiales	6	12	50%	12	6,00%
Residuos	3	7	43%	7	3,00%
Uso del suelo y ecología	4	10	40%	9,5	3,80%
Contaminación	5	12	42%	9,5	3,96%
Puntos Extraordinarios	1	10	10%	10	1,00%
Puntuación BREEAM					56,38%
Clasificación					Excelente

Tabla 2.9: Ejemplo de puntuación según BREEAM ES Viviendas. Fuente: Guía BREEAM

La certificación DGNB fue desarrollada por el Ministerio Federal de la vivienda durante dos años con la colaboración con el "Sustainable Building Council" Alemán. La primera guía que se realizó fue para la construcción de nuevos edificios de oficinas y edificios administrativos. El objetivo de la misma es la protección de los conceptos básicos como pueden ser el medioambiente, recursos, salud, cultura y dinero. Estos conceptos son derivados de las tres dimensiones de la sostenibilidad, economía, medioambiente, sociedad.

Está certificación se basa en el análisis del ciclo de vida de forma cuantitativa. Un ejemplo claro es que la eficiencia energética, no solo contempla el consumo energético en la fase de uso sino que también contempla la cantidad de energía requerida por la fabricación de los materiales.

El sistema de evaluación está organizado en tres niveles diferentes y un subnivel, de los que forman parte 6 Grupos principales de criterios, 11 Grupos de criterios, 46 Criterios y 150 indicadores, tabla 2.10.

3.Socio-Cultural and Functional Quality
3.1.Health, comfort and User Satisfaction
3.1.5 Visual Comfort
• Daylight availability, entire building
• Daylight availability, sationary workplaces
• Line of sight towards the exterior
• Nonglaring Daylight

Tabla 2.10: Niveles del sistema para edificios Sostenibles BNB. Fuente:Federal Ministry for Environment, Nature Conservation, Building and nuclear Safety.

Dentro de la certificación total, los 6 grupos tienen diferente importancia o peso, los aspectos Ecológicos tienen un peso del 22,5%, igual que los aspectos económicos y los socio culturales, la Calidad Técnica también representa el 22,5%, la Calidad del Proceso un 10%. Al mismo tiempo los criterios que forman parte del Grupo de criterios tienen una diferente importancia que se clasifica de 1 a 3 (factor de relevancia). La valoración de cada criterio se realiza mediante una puntuación que va de 10 a 100 puntos, donde 100 es el máximo y 10 es el mínimo, tabla 2.11.

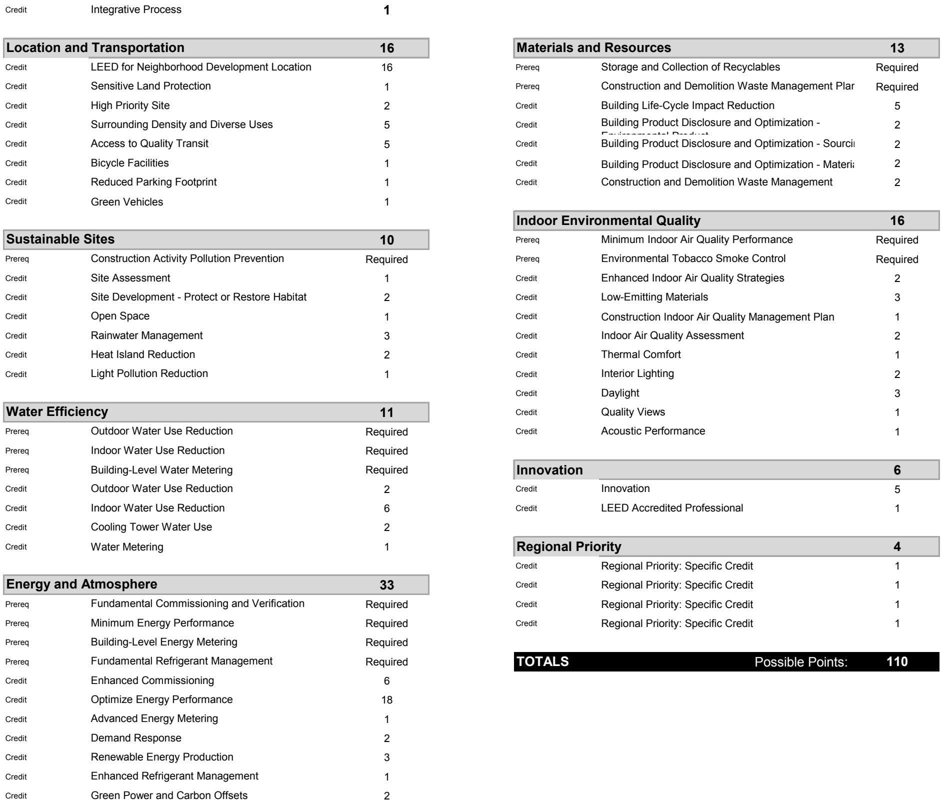
La clasificación final se obtiene mediante la ponderación de todos los criterios clasificando la certificación en función del porcentaje obtenido de puntos que van del "Bronze" con un mínimo del 50% al 65%, el "Silver" a partir del 65% hasta el 80% y el "Gold" por encima del 80%.

		Relevance Factor	% share of overall result	%Total
1	Ecological Quality			22,50%
1.1	Effects on global and local Environment		%	
1.1.1	Global warning potential	3	3,375	
1.1.2	Ozone Depletion potencial	1	1,125	
1.1.3	Photochemical Ozone Creation Potencial	1	1,125	
1.1.4	Acidification Potential	1	1,125	
1.1.5	Eutrophication Potential	1	1,125	
1.1.6	Risks to the local Environment	3	3,375	
1.1.7	Sustainable Logging /Wood	1	1,125	
1.2	Demand and resources			
1.2.1	Primary Energy Demand Not Renewable	3	3,375	
1.2.2	Tota primary demand and amount of Pere	2	2,25	
1.2.3	Fresh Water Demand and Quantity of Waste water	2	2,25	
1.2.4	Demand of Space	2	2,25	
2	Economic Quality			22,50%
2.1	Life Cycle Costs			
2.1.1	Building-related Life Cycle Costs	3	13,5	
2.2	Performance			
2.2.1	Value Stability	2	9	
3	Socio-Cultural and Functional Quality			22,50%
3.1	Health, Comfort and user satisfaction			
3.1.1	Termal comfort in winter	2	1,607	
3.1.2	Thermal Comfort in summer	3	2,411	
3.1.3	Indoor air Quality	3	2,411	
3.1.4	Acoustic Comfort	1	0,804	
3.1.5	Visual Comfort	3	2,411	
3.1.6	Influence of the user	2	1,607	
3.1.7	Outdoor Qualities	1	0,804	
3.1.8	Safety and Incident Risks	1	0,804	
3.2	Functionality			
3.2.1	Barrier-free building	2	1,607	
3.2.2	Space Efficiency	1	0,804	
3.2.3	Capability of Conversion	2	1,607	
3.2.4	Public Accessibility	2	1,607	
3.2.5	Bicycle Comfort	1	0,804	
3.3	Ensuring Design Quality			
3.3.1	Design and Urban Quality	3	2,411	
3.3.2	Art in Architecture	1	0,804	
4	Technical Quality			22,50%
4.1	Technical Execution			
4.1.1	Sound insulation	2	5,625	
4.1.2	Heat insulation and protection against Condensate	2	5,625	
4.1.3	Cleaning and Maintenance	2	5,625	
4.1.4	Dismantling, Searation and Utilisation	2	5,625	
5	Process Quality			10%
5.1	Managemnet and Design			
5.1.1	Project preparation	3	1,429	
5.1.2	Integrated Design	3	1,429	
5.1.3	optimisation and Complexity of planning	3	1,429	
5.1.4	Sustainability Issues in Tender and Placing	2	0,952	
5.1.5	Requeriments for an Optimal Utilisation and Management	2	0,952	
5.2	Building Construction			
5.2.1	Building site/Building Process	2	0,952	
5.2.3	Quality Assurance of the Building Construction	3	1,429	
5.2.4	Controlled Commissioning	3	1,429	
6	Location Profile			-
6.1	Location Profile			
6.1.1	Risks at the Micro-site	2	-	
6.1.2	Conditiond at the Micro-site	2	-	
6.1.3	Image and Character of location and Quarter	2	-	
6.1.4	Public trans`port connections	3	-	
6.1.5	Vicinity to Use-Specific Services	2	-	
6.1.6	Supply Lines/site development	2	-	

Tabla 2.11: Grupos principales de criterios, grupo de criterios, criterios, ponderación. Fuente:Federal Ministry for Environment, Nature Conservation, Building and nuclear Safety.

La certificación LEED se estructura de diferentes formas en función de la tipología de edificio. En el caso del LEED BD+C ("Building Design & Construction") se estructura en base unas categorías ("Credit Categories") que a su vez contienen un número de créditos, estos créditos se evalúan su cumplimiento mediante una puntuación. La suma de la puntuación nos indica el nivel de la certificación.

Las categorías a evaluar son: Proceso Integrado, Situación y transporte, Emplazamiento sostenible, Eficiencia del agua, Energía y atmosfera, Materiales y recursos, Calidad medioambiental del aire interior, Innovación y prioridad regional, tabla 2.12.



Credit	Integrative Process	**1**

Location and Transportation		**16**
Credit	LEED for Neighborhood Development Location	16
Credit	Sensitive Land Protection	1
Credit	High Priority Site	2
Credit	Surrounding Density and Diverse Uses	5
Credit	Access to Quality Transit	5
Credit	Bicycle Facilities	1
Credit	Reduced Parking Footprint	1
Credit	Green Vehicles	1

Sustainable Sites		**10**
Prereq	Construction Activity Pollution Prevention	Required
Credit	Site Assessment	1
Credit	Site Development - Protect or Restore Habitat	2
Credit	Open Space	1
Credit	Rainwater Management	3
Credit	Heat Island Reduction	2
Credit	Light Pollution Reduction	1

Water Efficiency		**11**
Prereq	Outdoor Water Use Reduction	Required
Prereq	Indoor Water Use Reduction	Required
Prereq	Building-Level Water Metering	Required
Credit	Outdoor Water Use Reduction	2
Credit	Indoor Water Use Reduction	6
Credit	Cooling Tower Water Use	2
Credit	Water Metering	1

Energy and Atmosphere		**33**
Prereq	Fundamental Commissioning and Verification	Required
Prereq	Minimum Energy Performance	Required
Prereq	Building-Level Energy Metering	Required
Prereq	Fundamental Refrigerant Management	Required
Credit	Enhanced Commissioning	6
Credit	Optimize Energy Performance	18
Credit	Advanced Energy Metering	1
Credit	Demand Response	2
Credit	Renewable Energy Production	3
Credit	Enhanced Refrigerant Management	1
Credit	Green Power and Carbon Offsets	2

Materials and Resources		**13**
Prereq	Storage and Collection of Recyclables	Required
Prereq	Construction and Demolition Waste Management Plar	Required
Credit	Building Life-Cycle Impact Reduction	5
Credit	Building Product Disclosure and Optimization -	2
Credit	Building Product Disclosure and Optimization - Sourci	2
Credit	Building Product Disclosure and Optimization - Materi	2
Credit	Construction and Demolition Waste Management	2

Indoor Environmental Quality		**16**
Prereq	Minimum Indoor Air Quality Performance	Required
Prereq	Environmental Tobacco Smoke Control	Required
Credit	Enhanced Indoor Air Quality Strategies	2
Credit	Low-Emitting Materials	3
Credit	Construction Indoor Air Quality Management Plan	1
Credit	Indoor Air Quality Assessment	2
Credit	Thermal Comfort	1
Credit	Interior Lighting	2
Credit	Daylight	3
Credit	Quality Views	1
Credit	Acoustic Performance	1

Innovation		**6**
Credit	Innovation	5
Credit	LEED Accredited Professional	1

Regional Priority		**4**
Credit	Regional Priority: Specific Credit	1
Credit	Regional Priority: Specific Credit	1
Credit	Regional Priority: Specific Credit	1
Credit	Regional Priority: Specific Credit	1

TOTALS	Possible Points:	**110**

Tabla 2.12: Categorías, créditos por categoría y puntuación. Fuente: USGBC.

La clasificación del esquema LEED BD+C para edificios nuevos y grandes rehabilitaciones es la siguiente, tabla 2.13.

Clasificación LEED	*Puntuación en puntos*
PLATINUM	80-110
GOLD	60-79
SILVER	50-59
CERTIFIED	40-49

Tabla 2.13: Niveles de clasificación según LEED. Fuente: USGBC

La certificación VERDE, sigue una metodología basada en una aproximación al análisis de ciclo de vida en cada fase y consiste en evaluar la reducción de impactos del edificio y su emplazamiento por la implementación de medidas, tanto en estrategias de diseño como en factores de rendimiento, agrupadas estas medidas en una lista de criterios de sostenibilidad. La certificación Verde también se estructura diferente en función del edificio a evaluar, tabla 2.14.

INFORMACIÓN DE PROYECTO • Optimización de la vida útil de la estructura	PARCELA Y EMPLAZAMIENTO • Clasificación y reciclaje de residuos en el edificio • Plantas autóctonas • Árboles para crear áreas de sombra • Efecto isla de calor • Efecto isla de calor en cubierta • Contaminación lumínica
ENERGÍA Y ATMÓSFERA • Uso energía no renovable en materiales • Energía no renovable en el transporte de materiales • Consumo de energía no renovable en el uso del edificio • Demanda energía eléctrica • Producción de energía renovable • Emisiones en combustión	RECURSOS NATURALES • Consumo de agua potable • Reutilización aguas de lluvia • Reutilización de aguas grises • Planificación demolición • Gestión residuos de la construcción • Impacto de los materiales distintos al consumo de energía
CALIDAD DEL AMBIENTE INTERIOR • Toxicidad de los materiales de construcción • Proceso de purga • Concentración CO2 aire interior • Limitación velocidad del aire • Eficiencia de la ventilación • Confort Térmico • Iluminación natural • Deslumbramiento en las zonas de ocupación • Nivel de la iluminación y calidad de la luz • Protección frente el ruido exterior • Protección del ruido de los recintos de instalaciones • Protección de los mismos recintos interiores.	CALIDAD DEL SERVICIO • Eficiencia de los espacios • Capacidad de control de la iluminación • Capacidad de control de los sistemas HVAC • Desarrollo e implantación de un plan de gestión de mantenimiento
ASPECTOS SOCIALES Y ECONÓMICOS • Acceso Universal • Derecho al sol • Acceso a espacios privados • Protección de las vistas desde el exterior • Acceso visual desde las áreas de trabajo • Coste de construcción • Coste de uso	

Tabla 2.14: Categorías y criterios según VERDE. Fuente: Guía Verde para EA GBCe

Cada criterio se le asocia una puntuación de referencia (“benchmark”). Estos valores se establecen a partir de revisión de la reglamentación de la región, el análisis de los valores de rendimiento usuales del edifico en la zona, o por consenso entre un grupo de expertos.

En la herramienta VERDE, la puntuación se establece de 0 a 5 , donde el 0 es valor de referencia que marca la normativa el 3 es una mejora media y el 5 corresponde a la mejor práctica posible. Al final del estudio estas puntuaciones se ponderaran en función del peso del impacto, tabla 2.15.

Cambio climático	27%
Aumento de la radiación UV a nivel del suelo	0%
Pérdida de fertilidad	5%
Pérdida de vida acuática	6%
Producción de cáncer y otros problemas de salud	8%
Cambios en la biodiversidad	4%
Agotamiento de energía no renovable	8%
Agotamiento de recursos no renovables	9%
Agotamiento de aguas potables	10%
Generación de residuos no peligrosos	6%
Salud, bienestar y productividad para los usuarios	12%
Riesgo financiero o beneficios para los inversores	5%

Tabla 2.15: Categorías de impacto y peso VERDE. Fuente: Guía Verde para EA GBCe

La clasificación del esquema VERDE NE Residencial para edificios nuevos es la siguiente, tabla 2.16.

Clasificación LEED	Puntuación en puntos
5 HOJAS	4,5-5
4 HOJAS	3,5-4,5
3 HOJAS	2,5-3,5
2 HOJAS	1,5-2,5
1 HOJA	0,5-1,5
0 HOJAS	0-0,5

Tabla 2.16: Niveles de Clasificación según VERDE. Fuente: Guía Verde para EA GBCe

3. ARTÍCULO “DEVELOPMENT OF A SCALE OF BUILDING CONSTRUCTION SYSTEMS ACCORDING TO CO2 EMISSIONS IN THE USE STAGE OF THEIR LIFE CYCLE”

Este capítulo presenta un estudio realizado para evaluar la eficiencia energética de los sistemas constructivos en su fase de uso, basado en un caso de estudio sobre una vivienda unifamiliar, el desarrollo de la metodología se focaliza en diferentes tipologías de cubiertas, siendo transferible a otros sistemas constructivos.

Este estudio fue presentado en un artículo titulado “Development of a scale of building construction systems according to CO2 emissions in the use stage of their life cycle”, publicado el 2 de Octubre de 2014 en la revista “Building and Environment” (Castellano et al., 2014)

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Development of a scale of building construction systems according to CO_2 emissions in the use stage of their life cycle

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ABSTRACT

Many different research papers have been written about sustainable building, outlining which indicators should be considered for the construction of sustainable buildings. However, due to the wide range of European, national and local regulations, the application of these indicators is complicated by numerous incongruencies. Furthermore, there are many definitions of concepts such as bio-construction, bioclimatic architecture, ecological building, sustainable construction and others which have the same objective. This paper aims to establish a procedure for facilitating the current system of environmental certification and at the same time, help apply the measures for sustainable construction by creating a scale of CO_2 emissions according to construction system. The methodology employed is based on the standardized systems of simulation and classification of energy efficiency in Spain, although they could be adapted to systems used in other countries. Applying this methodology to a case study enables the conclusion that the value obtained from the different simulations of the whole building with the different typologies of roofing proposed have a classification A and B, and when the different roof typologies are studied separately, they are classified as A, B and C. This methodology simplifies the decision-making process at an environmental level and also in terms of energy efficiency so that decision-making can be carried out at the architectural design stage and not subsequently, when energy simulations are currently carried out. The results will enable the application of the scale obtained as a new indicator in the definitions of construction systems.

1. Introduction

The carbon footprint [1] is used to establish the environmental impact we have on our planet, taking into account human population [2], the increase in emissions of pollutants and the consumption of different natural resources, which may be unsustainable in the near future. Different organizations have already regulated measures to reduce environmental impact and for example in the case of Europe, The Energy Performance Building Directive (EPBD) was established by the European Commission [3,4] as a reference framework for the development of national regulations taking into account variations in the local conditions of the community states.

Construction, the uses of buildings and their waste have a significant impact on the environment. The concept of sustainable construction is therefore important, thus sustainability is defined as a balance of social, economic and environmental factors [5]. It would therefore be useful to distinguish between concepts such as bio-construction, bioclimatic architecture, ecological construction and the many others which appear in research papers [6].

The developed world is now aware of the impact on the environment produced by the building sector in any of the three stages of the life cycle (Fig. 1).

For example it can be seen that in Switzerland the building sector represents 50% of energy consumption [7], and how this consumption is distributed within this sector can also be observed. Also, Zöld and Szalay [4] indicate that energy consumption in Europe is between 40% and 50%, and similarly, Erlandsson and Borg [8] show that energy demand for the building sector is between 30% and 40%. In the case of the USA similar results are obtained as can be seen in the work by Der-Petrossian et al [9].

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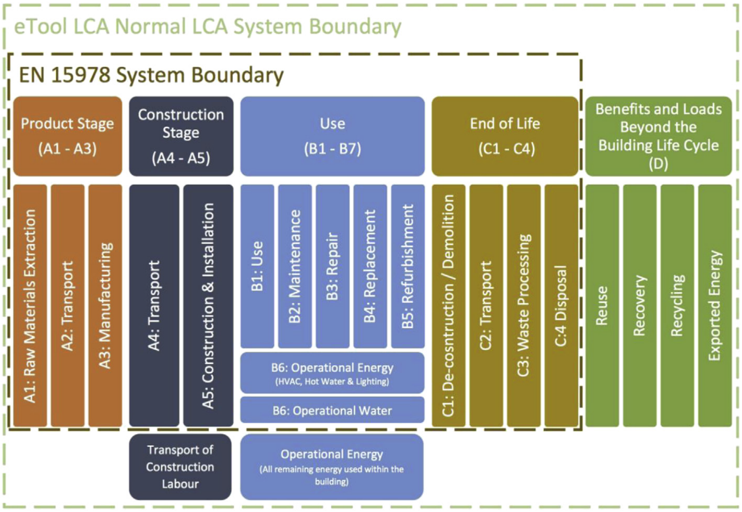


Fig. 1. Life cycle stages of a building EN 15978:2011.

In relation to the resources of materials used in construction, these represent 44% [10] of total building resources. It can also be said that more than 50% of raw materials extracted from the Earth are transformed into products and materials for construction [11].

In economic terms, construction represents 10% of world GDP per year, 30% for Europe, 22% for the USA, 21% for Japan, 4% for the rest of the developed world and 23% in the developing world [12]. In financial terms, in 2004 it represented a total production of €1305 billion in EU-27 [13].

In terms of the environment, this represents one third of CO_2 emissions [10], or it may also be said that in Europe 35% of greenhouse gases derive from the construction sector according to the EU report [11]. Waste from building and demolition (C&DW) has risen to over 450 million tons per year in the EU [13].

In social terms, the construction industry represents 7.3% of total employment in the EU, not including the manufacturing industry and post construction services such as building maintenance [13]. Industry represents 29.1% of the workforce, which means that in total terms 44.6 million workers in the EU depend directly or indirectly on the building sector [14]. The residential sector represents 46% of total EU production, the non-residential sector 31% and civil engineering 23%. The building sector is characterized by a long service life of several (or even more) decades, a slow replacement rate of building stock (about 1% per year) and a much lower rate for building demolition (about 20 times less than new construction) [14].

In order to analyze the impact from the 1970s onwards, the first life-cycle analysis (LCA) studies of specific products such as containers were carried out [15], but it was not until the 1990s that institutions such as SETAC (Society of Environmental Toxicology and Chemistry), BUWAL (Bundesamt für Umwelt, Wald und Landschaft), US-EPA (United States Environmental Protection Agency), Nordic Council, ISO (International Organization of Standardization) [15], among others, began to define procedures for the study of LCA, until the beginning of the 21st century, when ISO was established as LCA standardization.

From here onwards LCA studies became frequent, considering different types of impact, such as potential global warming, depletion of stratospheric ozone, potential acidification, potential eutrophication, the potential formation of photo oxidants, potential human toxicity, potential eco toxicity, all of which are associated with climatic change [16].

In the construction sector, the LCM (Life Cycle Management) study by Ortiz et al. [12] estimates that between 80 and 92% of environmental impact corresponds to the 6 categories produced in the use stage. It should also be noted that the LCA base analysis carried out [17], which only includes analysis of primary energy in the use stage and the absorbed energy of the materials, represent 69% and 31%, respectively. One of the most detailed articles written about sustainability in the construction sector is that of Ortiz et al. [16] which is based on concepts, tools and the scope of LCA.

This paper aims to establish a procedure which facilitates and improves the current system for environmental certification and at the same time, to help with the application of measures for sustainable construction with the creation of a scale of CO_2 emissions applied to construction systems which will be directly related to the energy consumption of the building in its use stage of the life cycle. The priority for the parameter obtained is its ease of application by all those involved in the building and construction process. The procedure characterizes CO_2 emissions on construction systems trough new scale and it helps to building designers at design step with new environmental and efficiency parameter to take building decisions.

2. Life-cycle assessment in construction

Life-cycle analysis methodology (LCA) is based on international regulations ISO 14044:2006 and ISO 14040:2006, and in the case of the building sector in Spain UNE EN 15978:20011, and UNE EN 15804. LCA consists of four different stages: definition of objectives and the area of application, analysis of the inventory, evaluation of impact, and finally interpretation of the results [18]. Definition of the objectives and the scope of application require definition of the aim, the limits of the building part and the level of detail. Analysis of the inventory consists of analysis of the data for each unit of the process established in the life cycle being evaluated, considering all input and output of the indicators for each category of impact. Evaluation of impact corresponds specifically to the evaluation of the impact on the environment, and the final step is interpretation, which aims to identify important issues, to evaluate the results in order to draw conclusions and to formulate recommendations [19].

Different building environmental assessment tools have been developed (Table 1). In fact Haapio and Viitaniemi [20] propose two types of classification [20].

Not all the environmental assessment tools consider all the stages of the life cycle, or use the same criteria, or consider the importance of the different stages in the same way. Some of these tools emphasize the importance of use and maintenance while others focus on production or construction (Table 2).

This investigation is focused on the use stage (B1–7 of the UNE 15978:2011), specifically with regard to CO_2 emissions produced in the service stage (B6 de la UNE 15978:2011) (Fig. 1).

3. Legal framework vs. LCA

Different legislation exists for the evaluation of CO_2 emissions. In this section some of the most important ones in terms of Life Cycle Assessment (LCA), which is the methodology used for the development of the classification carried out in this research paper, will be shown. The legislation presented in the following section provides a reference point for the tool which has been developed.

3.1. European directive 2010/31/EC vs. LCA

The European directive 2010/31/EC aims to promote the energy efficiency of buildings in the European Union, taking into account exterior climatic conditions and particular locations, as well as interior environmental requirements and profitability in terms of cost-efficiency [21].

This directive establishes requirements in relation to:

a) The general common framework for a methodology for calculating the integrated energy efficiency of the buildings or the units of the building.
b) The application of minimum requirements for the energy efficiency of new buildings and new units of buildings.
c) The application of minimum requirements for energy efficiency of:
    a. Buildings and units and elements of existing buildings which are being significantly refurbished.
    b. Elements of construction which form part of the surroundings of the building and have significant repercussions on the energy efficiency of the surroundings being modernized or replaced.
    c. Technical installations of the buildings when they are installed, replaced or improved.
d) The almost complete lack of national plans aimed at increasing the number of buildings of energy consumption.
e) The energy certification of buildings or units of buildings.
f) The inspection period for the building heating and air-conditioning installations.
g) The control systems which are independent from energy efficiency certificates and inspection reports.

The directive proposes the concept of energy efficiency and the application of a common framework for obtaining profitability in

Table 1
Building environmental assessment tools.

Name	Developer	References
ATHENA™ Environmental Impact Estimator	ATHENA Sustainable Material Dinstitute; Canada	ATHENA Institute (2003); ATHENA™; DOE (1996/2006); Trusty amb Meil (2002a.b)
BEAT 2002	Danish Building Research Institute (SBI), Denmark	BEAT (2002): Forsberg and von Malmborg (2004): Hansen (2005); IEA Annex 31 (2001); Petersen (2002a,b)
BeCost (Previouscly known as LCA-house)	VTT, Finliand	BeCost; CRISP (2004); IEA Annex 31 (2001)
BEES 4.0	U.S. National Institute of Standards and Technology (NIST), USA	BEES 4.0; DOE (1996/2006); IEA Annex 31 (2001); Lippiatt (2002); Trusty (2003)
BREEAM	Building Research Establishment (BRE), UK	BREEAM; BREAM fact file; CRISP (2004); Grace (2000); IEA Annex 31 (2001)
EcoEffect	Royal Institute of Technology (KTH), Sweden	CRISP; EcoEffect; Forsberg and von Malmborg (2004); Glaumann (2000); IEA Annex 31 (2001)
EcoProfile	Norwegian Building Research Institute (NBI), Norway	Boonstra and Pettersen (2003); IEA Annex 31 (2001); Pettersen (2000a,b); Pettersen et al. (2000)
Eco-Quantum	IVAM, the Netherlands	CRIPS; EcoQuantum; IEA Annex 31 (2001); Peuportier and Putzeys (2005)
Envest 2	Building Research Establishment (BRE), UK	DOE (1996/2006); CRISP; Enverst 2; IEA Annex 31 (2001); Peuportier and Putzeys (2005)
Environmental Status Model (Miljöstatus)	Association of the Envioronmental Status of Buildings, Sweden	Boonstra and Pettersen (2003); Environmental Status Model; Carlson (2000); Carlson and Lundgren (2000)
EQUER	Ècole des Mines de Paris, Centre d'Énergétique et Procédés France	DOE (1996/2006); EQUER; IEA Annex 31 (2001); Nivel and Rialhe (2000); Peuportier and Putzeys (2005)
ESCALE	CTSB and the University of Savoie, France	ESCALE; Gerad et al. (2000); IEA Annex 31 (2001)
LEEDR	U.S. Green Building Council, USA	CRIPS; IEA Annex 31 (2001); LEEDR, LEEDR (2005)
LEGEP (previously known as Legoe	University of Karlsruhe, Germany	IEA Annex 31 (2001); Kohler et al. (2005); LEGEP Peuportier and Putzeys (2005)
PAPOOSE	TRIBU, France	IEA Annex 31 (2001); Nibel and Rialhe (2000); PAPOOSE
TEAM™[a]	Ecobilan, France	IEA Annex 31 (2001); Nibel and Rialhe (2000); TEAM™
EnerBuiLCA	SUDOE. The programme of Territorial coperation of the space Southwest European	UNESCO-ESCi; TECNALIA; iMat; IAT; CTCV; NOBATEK; LNEG

[a] ATHENA™ is a professional LCA-tool, for evaluating the life cycle, environmental and cost profiles of products and technologies, including buildings. It is the only in this table that is not speciafically for environmental assessment of buildings. However, it can be used for buildings for example as product comparison tool and information resource.

Table 2
Stages of the life cycle.

ATHENA classification	Assessment tool	Production	Constrution	Use/operation	Maintenance	Demolition	Disposal
1	BEES 4.0	x		x	x		x
	TEAM™	x	x	x	x		x
2	ATHENA™	x	x		x		x
	BEAT 2002	x	x	x	x		x
	BeCost						
	Eco-quantum	x	x	x	x	x	x
	Envest 2	x	x	x	x	x	x
	EQUER	x	x	x	x	x	x
	LEGEPR		x	x	x	x	
	PAPOOSE	x		x	x	x	x
3	BREEAM	x	x	x	x		x
	EcoEffect	x	x	x	x	x	x
	EcoProfile			x	x		
	Environmental status model						
	ESCALE	x	x	x	x		
	EnerBuiLCA	x	x	x	x		
	LEDDR	x	x	x	x	x	x

terms of cost-efficiency in the use stage of the building, while the systems based on LCA consider the overall building work (Fig. 1).

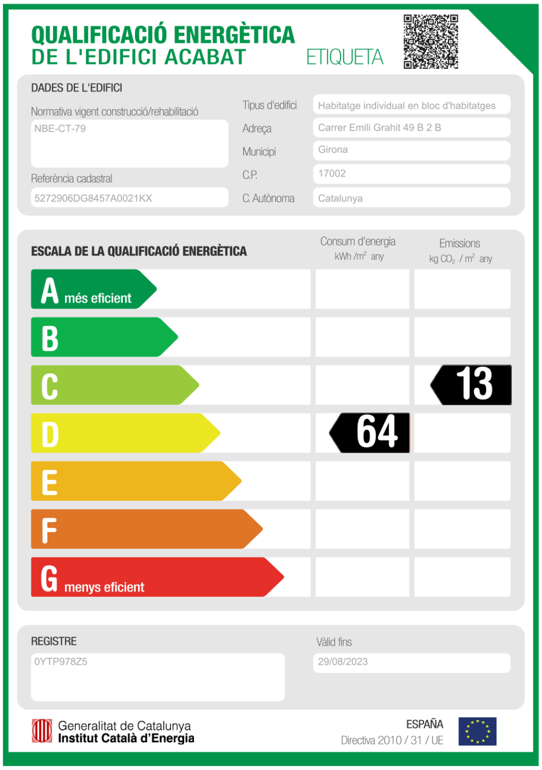
3.2. Legal framework on building certification in Spain vs. LCA

The procedure for obtaining the energy efficiency certificate for newly constructed buildings, high level rehabilitations and existing buildings is promoted by the Royal Decree 235/2013, 5th April [22]. This Royal Decree originates from Directive 2010/31/EC [3] of the European Parliament, which establishes the obligation of member states to provide objective information about the energy characteristics of the buildings, so that users are aware of their energy qualification. This regulation has two objectives: firstly, to establish the basic procedure for calculating the energy efficiency qualification in order to subsequently carry out the energy certification, and secondly, to pass a common distinction at a national level known as an 'energy efficiency label'. For the energy qualification and certification of a building to be correctly done, either for residential use or for tertiary use, the following procedure must be followed for new buildings:

a. Obtain the energy qualification for the building during the project stage through one of the options that Royal Decree 235/2013 determines to be recognized documentation, from the following computer simulation programs:
    i) General option of qualification, CALENER VIP or CALENER GT depending on their classification as residential buildings, small commercial buildings, medium-sized buildings or large buildings in the tertiary sector.
    ii) Simplified option of energy efficiency qualification for housing, for which the CERMA program [23] is a primary example.
b. Obtain the energy efficiency certificate for the finished building, which supposes that the certificate obtained during the project stages conforms to the checks and inspections during the construction stage of the building. The efficiency certificate for the finished building will be undersigned by the project management team and will state that the building has been constructed according to the project specifications and, as a result, this certifies the energy efficiency of the project.

The energy efficiency classification obtained during the project stage, construction stage or for the constructed building, will be adjusted accordingly to a classification rating from A to G (Fig. 2).

The CALENER VIP and CALENER GT systems provide the calculation of energy use for cooling or heating the building together with the energy required for domestic hot water in the case of housing. These calculations are translated into final energy, primary energy consumed and CO_2 emitted. These programs obtain the energy efficiency calculation with C1 and C2 indexes which include CO_2 emissions, the average value of $CO_{2,}$ as established by


QUALIFICACIÓ ENERGÈTICA
DE L'EDIFICI ACABAT ETIQUETA

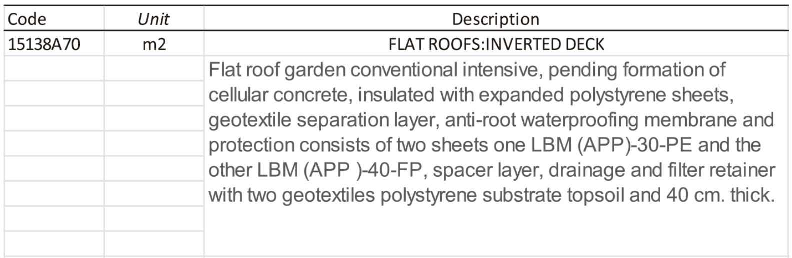
DADES DE L'EDIFICI
Normativa vigent construcció/rehabilitació: NBE-CT-79
Referència cadastral: 5272906DG8457A0021KX
Tipus d'edifici: Habitatge individual en bloc d'habitatges
Adreça: Carrer Emili Grahit 49 B 2 B
Municipi: Girona
C.P.: 17002
C. Autònoma: Catalunya

ESCALA DE LA QUALIFICACIÓ ENERGÈTICA
Consum d'energia kWh /m² any
Emissions kg CO_2 / m² any

REGISTRE: 0YTP978Z5
Vàlid fins: 29/08/2023

Generalitat de Catalunya
Institut Català d'Energia
ESPAÑA
Directiva 2010 / 31 / UE

Fig. 2. Energy label from the energy classification process.



Code	*Unit*	Description
15138A70	m2	FLAT ROOFS:INVERTED DECK
		Flat roof garden conventional intensive, pending formation of cellular concrete, insulated with expanded polystyrene sheets, geotextile separation layer, anti-root waterproofing membrane and protection consists of two sheets one LBM (APP)-30-PE and the other LBM (APP)-40-FP, spacer layer, drainage and filter retainer with two geotextiles polystyrene substrate topsoil and 40 cm. thick.

Fig. 3. Example of specification of a construction system work package.

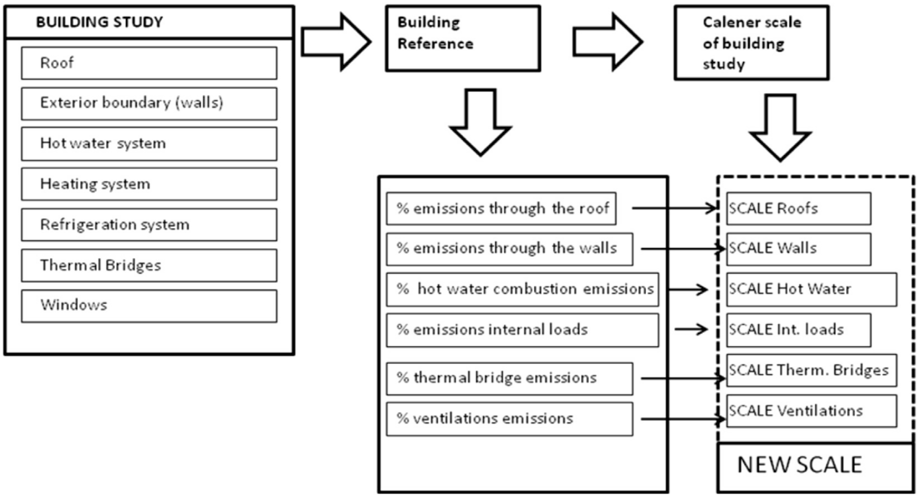


Fig. 4. General structure of the proposed methodology.

Technical Building Code (CTE) [24] in the section HE (Energy ng) for new buildings [25].

irstly, it must be noted that with respect to LCA, this system serves for the conversion of final energy with CO_2 emissions gas combustion (natural gas, oil), and the emissions produced electricity consumption not including lighting. Secondly, it is sidered that the energy produced by all renewable energies mass, bio-fuels, solar PV and solar thermal) have zero emissions , and do not include the emissions which may be generated by creation of these energies even if Spain or Europe are producers of these. Thirdly, this calculation methodology is limited to heat refrigeration and domestic hot water services, except in the cas CALENER GT (large tertiary) which includes electricity consum tion. Fourthly, the calculation only includes the use stage of I specifically stage B6, energy use during the use stage. There none of the suppositions include the other stages of the life cy Neither do they consider building work and maintenance op tions for the building during their useful life, nor do they cons the deconstruction process or waste treatment which this ma tenance may generate.

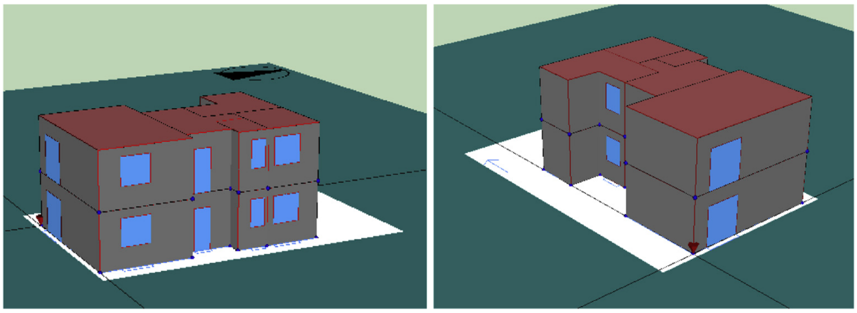


Fig. 5. Different perspectives of the reference building.

Table 3
Inventory construction of the building.

Enclosure	U (W/m^{2}K)	Material layers	Thickness of the layers (m)
External wall	0.26	1/2 Metric Catalan solid brick pedestal (40 mm < thickness < 50 mm)	0.115
		Morter	0.01
		Unventilated air chamber	0.05
		EPS-expanded polystyrene (0.037 W/mK)	0.04
		Double hollow brick partition (60 mm < thickness < 90 mm)	0.07
		Plaster skimming (1000 < r < 1300)	0.01
Internal wall	2.65	Plaster skimming (1000 < r < 1300)	0.01
		Double hollow brick partition (60 mm < thickness < 90 mm)	0.06
		Plaster skimming (1000 < r < 1300)	0.01
Internal foundation	0.76	Floor tiles	0.01
		Ciment or lime mortar for bricklaying and for rendering or skimming (1000 < r < 1250)	0.4
		EPS-expanded polystyrene (0.037 W/mK)	0.03
		Unidirectional slabs with concrete beam filling (depth 250 mm)	0.25
		Plaster skimming (1000 < r < 1300)	0.01
Ground foundation	0.6	Floor tiles	0.01
		Ciment or lime mortar for bricklaying and for rendering or skimming (1000 < r < 1250)	0.2
		EPS-expanded polystyrene (0.037 W/mK)	0.05
		Reinforced concrete (2300 < r < 2500)	0.2
		Gravel	0.25
Roof	0.22	Roof planting soil	0.4
		Filter layer	0.001
		Drainage	0.1
		Membrane protection and root barrier	0.003
		Waterproofing	0.01
		EPS-expanded polystyrene (0.037 W/mK)	0.07
		Cellular concrete	0.011
		Unidirectional slabs with concrete beam filling (depth 250 mm)	0.1
		Plaster skimming (1000 < r < 1300)	0.01
window	1.8	Low emissive double glazing, 4 mm thick each, and air space of 12 mm.	0.02
window frame	2.2	High medium density wood	0.12

The energy efficiency evaluation system based on CALENER does not differ greatly from other evaluation systems which may give similar results [26], but it is true that the different types of simulations do not facilitate comparison of the results obtained. The creation of a methodology which takes into account a common benchmarking would therefore be very useful so that all the countries in Europe could compare results.

3.3. Characteristics and structure of Spanish building projects

In order to be able to develop a CO_2 emissions evaluation methodology, familiarity with the structure of a Spanish Building project is important. While the aim of the present paper is not to provide a detailed study, the structure of Spanish construction projects is summarized, allowing for the inclusion of the environmental construction system classification.

3.3.1. Structure of the projects

The structure of the Spanish building projects is defined by different regulations, national, regional, local or supra-municipal. The one with the principal impact on the overall project is the national regulation, specifically the CTE [24].

Appendix I, Part I of the CTE includes the contents of the project, which may be summarized as: Chapter I Technical Report, Chapter II Construction Report, Chapter III Completion of CTE with all appendices, plans and conditions, Chapter IV Measurements and Chapter V Budget. In the Spanish project, the composition of the construction elements are specified in Chapter IV, measurements and, as in other countries, this specification is carried out on the drawing plans. It would therefore seem appropriate to include a new field which indicates the environmental category together with the specification of the components of the construction systems, which currently are not included.

3.3.2. Measurements

This chapter of the regulation is related to the methodology developed for this paper, specifically with a new field to express the efficiency parameter as indicated by letters A to G.

According to the technical code, measurements will be done in stages, grouped into their corresponding sections for the work to be carried out on the building and must contain all the necessary technical descriptions for specification and evaluation.

Regulation UNE 157001:2002 [27] establishes the general criteria for the elaboration of projects and specifically, in the section for measurements, it establishes certain general considerations so that the project has a determined certifiable quality.

The measurements determine that the number of units must be included together with a definition of the characteristics, models, types and dimensions for each lot of work or element of the project. It also recommends the international system of units given in regulation UNE 82100 [28]. As to the contents, it will begin with an index which refers to each document, to the chapters, sections or sub-sections, with the aim of facilitating use. Furthermore, it will contain a complete list of the work lots which make up the total project.

Therefore the actual structure of a work package comprising of the measurements will consist of the code, a short description, a longer detailed description and a measurement unit (Fig. 3).

4. Simplified model of the certification of the energy efficiency of the construction system

The methodology which has been developed provides an automatic way to choose the most energy efficient construction system. As to its relationship with life cycle analysis, this scale will affect the use stage which represents 88.9% of total emissions [12] and it will therefore directly affect decisions technical experts make on the selection of the most sustainable and energy efficient construction system.

e 4
s alternatives analysis.

de	Code BEDEC	*U* (W/m^{2}K)	Description	Weight (kg/m^2)	Kwh/m^2	KgCO$_2$/m^2	€/m
M1	15138A70	0.22	Flat roof garden conventional intensive, pending formation of cellular concrete, insulated with expanded polystyrene sheets, geotextile separation layer, anti-root waterproofing membrane and protection consists of two sheets one LBM (APP)-30-PE and the other LBM (APP)-40-FP, spacer layer, drainage and filter retainer with two geotextiles polystyrene substrate topsoil and 40 cm thick.	475.63	222.86	119.65	113.
M2	15113TDF	0.29	Inverted roof sloping concrete walkable cell separating layer, waterproofing membrane with a flexible PVC sheet not weatherproof, insulated with extruded polystyrene plates 50 mm thick, with geotextile separation layer and finished with a pavement terrazzo on supports	240.03	253.37	131.74	89.
M 3	15123BCH	0.3	Inverted roof with slopes not passable aerated concrete, separating layer, waterproofing membrane with a surface density of 1.3 kg/m^2 and a 1 mm thick cardboard by unregenerate synthetic rubber (butyl), insulated with extruded polystyrene plates 40 mm, with geotextile separation layer and finish layer roof boulder protection.	193.76	164.02	99.62	42.
M 4	15127M05	0.44	Not passable cover with vapor barrier/sealing with polyethylene sheet, pending formation of expanded clay poured into dry, protective layer of cement mortar, membrane protection layer of mortar, separating layer of waterproofing with a membranous surface density sheet 3.8 kg/m^2 with bitumen sheet modificaco LBM (SBS)-40-FV + FP 50 g/m^2 to 130 g/m^2 geotextile separation layer roof and finishing concrete protection layer light Expanded Clay.	145.97	150.94	54.36	45.

Description of the process

he methodology developed begins with the introduction of for the construction systems of the building being studied. All he data for the construction systems are compared with a rence building, which together with the corresponding energy ulations in the base of the CALENER program provide an alphaerical scale from A to G. The energy simulation with the CERMA gram also provides % values of CO$_2$ for each of the construction ems (Fig. 4).

Generally the aim is to define a study building which, with the ENER energy simulation program, not only can have an A sification, but also the building classification scale and all ssions are obtained as well.

s the building studied is subjected to an energy simulation by CERMA program, emission percentages for the building coments are obtained. These components will be the following: fs and covered areas, domestic hot water (ACS), internal load, mal bridges, ventilation and finally, openings.

he combination of the general scale obtained with CALENER the percentages for the different components obtained with MA allow us to obtain the different scales for each of the

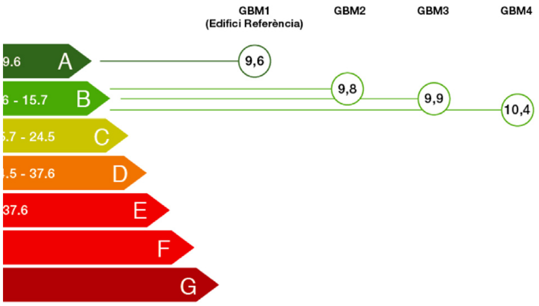


Fig. 6. Building classification.

construction systems (marked in a dotted line in Fig. 4). Until n regulations were unable to evaluate separately the energy ciency classification of the construction systems and assign a sc This means, as previously mentioned, by adding the scale to definition of the construction system, according to Fig. 3, even n value and innovation is given to the construction project.

4.2. Case study

In order to demonstrate the viability of the developed m odology, it has been applied to a case study of different typolo of a unique construction system for the roof. The study will onl made in the operational stage or the use stage of the life cycle of building. The construction systems of the study are obtained fro database called BEDEC [29], which contains information ab what constructions systems are made and composed abou terms of material and quantity of material. This indicates how construction system is formed per unit of measurement an description. This will provide a new parameter to be incorpor into this database, in this case environmental, consisting of corresponding energy qualification from A to G and this ma used in execution projects, simplifying or removing the pro established with CALENER VIP and CALENER GT and simplifying work of those involved in design of construction projects. The us the BEDEC database is due to its optimum suitability to the cesses of the construction sector in Spain; it is also one of the n widely used. From the regulation point of view, the case prop adopted constructive solutions in accordance with the anticip specifications in the Technical Building Code [24]. The final re will be values which will help to establish requirements relate sustainability (environmental, social and economic) which enable certification of the efficiency of the constructive process scale from A to G.

For the case study, a residential dwelling of 134.02 m^2 considered (Fig. 5). The building consists of the exterior shell of building, exterior boundary (walls), openings (windows) and roof, a radiating floor heating system and domestic hot water f a 15 Kw natural gas condensation boiler with performance of 1

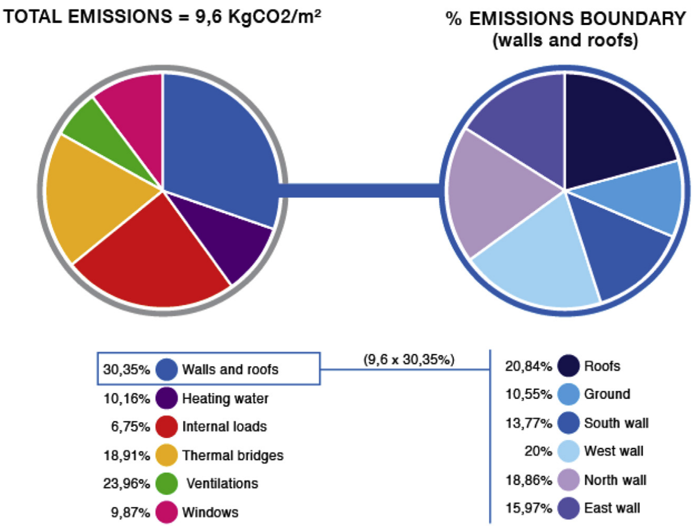


Fig. 7. Compositions of emissions in %.

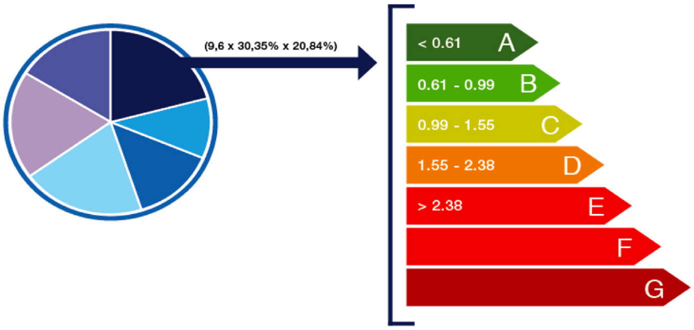


Fig. 8. General roof classification scale.

with solar power supply of 70%. Cold air is produced by an air–air system with nominal refrigeration capacity of 4.0 Kw (Table 3). The dwelling is located in the city of Barcelona (Catalonia, Spain), with a climatic classification of C2 [29].

The aim is to study the four types of construction systems for roofing (Table 4) of differing characteristics (one is that used in the building in the study) extracted from the database BEDEC, and establish which value they have on the scale, so as to be able to evaluate their impact on energy classification.

Through the simulation in the CALENER program, the classification for the building being studied is obtained with roof cover GBM1. Simulations are also carried out with the other proposals GBM2, GBM3, GBM4 (Fig. 6). Numbers of this classification are based on reference building thus these numbers will vary depending on system construction conditions.

Using the CERMA simulation program, the percentage of emissions is obtained for each of the construction systems. In numerical terms, it is established that the construction system of roofing and cover is 30.35% of 9.6 Kg CO_2/m^2 (Fig. 7).

From the combination of the roof and cover, the percentage corresponding to the roof will be taken, in this case 20.84%, and this will enable a classification of the roof alone according to the methodology proposed in this paper. Numerically, the results show 9.6 Kg $CO_2/m^2 \times$ 30.35% of loss through the roof and cover × 20.84% of loss for the cover (Fig. 8). This is the value for the roof proposed as option GBM1.

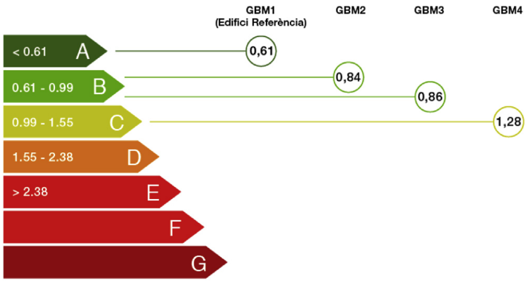


Fig. 9. Roof classification for the case study.

Table 5
Roofs analysis results.

Code	Unit	Description	Environmental and efficiency parameter
15138A70	m2	FLAT ROOFS:INVERTED DECK Flat roof garden conventional intensive, pending formation of cellular concrete, insulated with expanded polystyrene sheets, geotextile separation layer, anti-root waterproofing membrane and protection consists of two sheets one LBM (APP)-30-PE and the other LBM (APP)-40-FP, spacer layer, drainage and filter retainer with two geotextiles polystyrene substrate topsoil and 40 cm thick.	**A**
15113TDF	m2	Inverted roof sloping concrete walkable cell separating layer, waterproofing membrane with a flexible PVC sheet not weatherproof, insulated with extruded polystyrene plates 50 mm thick, with geotextile separation layer and finished with a pavement terrazzo on supports	**B**
15123BCH	m2	Inverted roof with slopes not passable aerated concrete, separating layer, waterproofing membrane with a surface density of 1.3 kg/m^2 and a 1 mm thick cardboard by unregenerate synthetic rubber (butyl), insulated with extruded polystyrene plates 40 mm, with geotextile separation layer and finish layer roof boulder protection.	**B**
15127M05	m2	Not passable cover with vapor barrier/sealing with polyethylene sheet, pending formation of expanded clay poured into dry, protective layer of cement mortar, membrane protection layer of mortar, separating layer of waterproofing with a membranous surface density sheet 3.8 kg/m^2 with bitumen sheet modificaco LBM (SBS)-40-FV + FP 50 g/m^2 to 130 g/m^2 geotextile separation layer roof and finishing concrete protection layer light Expanded Clay.	**C**

The next step is the simulation of all construction systems proposed in the CERMA program following the procedure established above, and from that, the percentage of losses in CO_2 emissions will be obtained for the roof for each of the proposed construction solutions.

At the end of the process the data will be put into a classification table generated for the building being studied (Fig. 5) and a classification linked to CO_2 emissions will be obtained (Fig. 9). One way to present the results for the different construction systems for the different roofs is expressed in Table 5. In this table, we can see a new column with the energy efficiency scale and therefore this helps to select the best solution in environmental terms.

5. Conclusions

It should be noted that energy consumption is not directly proportional to CO_2 production because there are energy production systems which emit more CO_2 than others; while it is not because of this that the building stops consuming less energy there is, in general, a direct connection. Therefore it is important that countries improve the energetic mixes by increasing the production of electric energy with renewable energies.

In order to act on energy consumption during the use stage it is vital to act during the design stage of the building, when the construction systems are defined and where it has been shown that steps may be taken to vary the CO_2 emissions generated, by limiting demand. This has great relevance for the construction of buildings of low demand or otherwise known as regionally adapted passive housing.

The normal production process in the design stage of a building is to select the construction systems according to architectural design and carry out the energy simulation CO_2 emissions later, and this may in fact lead to unnecessary costs in terms of time, resources and money.

This paper has created a system which enables the classification of different construction solution options in order to facilitate and improve the choice of construction system. Assigning an energy scale will help the design team prior to the choice of system and avoid running the simulation at the end of the architectural process.

The methodology created in this work and validated in the case study may be applied to other construction systems such as facades, windows, installations, etc. It also enables more sustainable construction, starting at the design stage.

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4. ARTÍCULO “DEVELOPING A SIMPLIFIED METHODOLOGY TO CALCULATE CO2/M2 EMISSIONS PER YEAR IN THE USE PHASE OF NEWLY-BUILT, SINGLE-FAMILY HOUSES”

Este capítulo presenta un estudio realizado para desarrollar una metodología simplificada para el cálculo de las emisiones de CO2/m2 año en la fase de uso de viviendas unifamiliares de nueva construcción, esta metodología se ha desarrollado mediante un caso de estudio sobre una vivienda unifamiliar.

Este estudio fue presentado en un artículo titulado “Developing a simplified methodology to calculate CO2/m2 emissions per year in the use phase of newly-built, single-family houses”, aceptado el 16 de septiembre en la revista “Energy and Buildings” (Castellano et al., 2015).

DEVELOPING A SIMPLIFIED METHODOLOGY TO CALCULATE CO2/ M2 EMISSIONS PER YEAR IN THE USE PHASE OF NEWLY-BUILT, SINGLE-FAMILY HOUSES

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Abstract

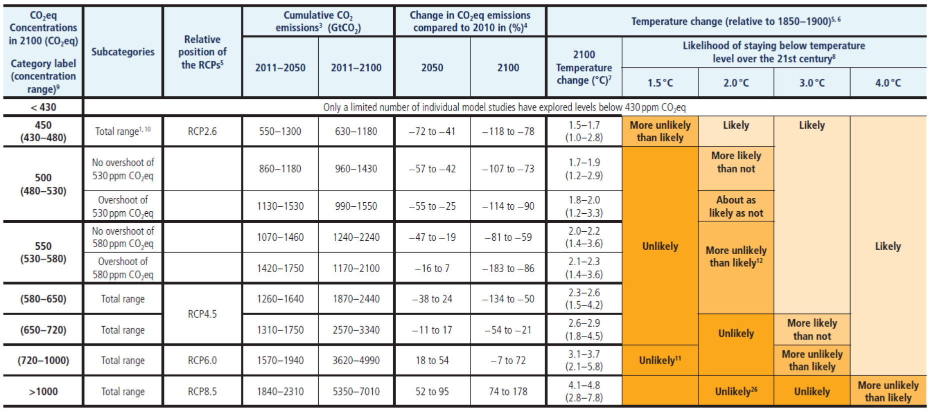
By 2020, different European Directives on the energy performance of buildings (EPBD) aim to reduce energy consumption by 20%, reduce greenhouse gas emissions by 20% and endorse a target of a 20% share of energy from renewable sources. These Directives have led EU Member States to develop systems, following their corresponding transposition into national law, to evaluate the energy efficiency of buildings, and create different Energy Performance Certificates (EPCs). This has led to different energy efficiency measurement systems in the EU and a CO2 emissions scale has not been included by some Member States. Just as EPC is aimed at influencing the demand for energy-efficient buildings, this study is aimed at developing a straightforward procedure to obtain the environmental impact in the use phase of a building in KgCO2/m2.year in order to influence the demand for buildings with a low impact on climate change. By applying this methodology to different case studies, we can conclude that obtaining the formula drastically simplifies the calculation of CO2 emissions in KgCO2/m2.year.The results obtained from applying this methodology will serve to record CO2 emission rates in single-family houses on a yearly basis, thus contributing to the study of applications that address climate change mitigation.

Keywords: Environmental building; CO2 emissions; sustainability indicators; Energy Performance Buildings Directive (EPBD); Energy Performance Certificate (EPC)

1. Introduction

According to studies carried out by NOAA (National Oceanic and Atmospheric Administration), NASA (National Aeronautics and Space Administration) and the Met Office Hadley Centre, and later confirmed in studies by Richard A. Muller and Robert Rohde [1][2], the Earth's temperature has been demonstrated as having increased by 1ºC in the last 50 years and by 1.5ºC in the last 250 years as a result of climate change. At the same time, the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC)[3] has predicted different scenarios, in which the average temperature will have increased by between 2.5ºC and 7.8ºC between 1900-2100 (Table 1), unless mitigation measures are taken.

Table 1. Key characteristics of the scenarios collected and assessedby WGIII AR5[3]



CO_2eq Concentrations in 2100 (CO_2eq) Category label (concentration range)[9]	Subcategories	Relative position of the RCPs[5]	Cumulative CO_2 emissions[3] ($GtCO_2$)		Change in CO_2eq emissions compared to 2010 in (%)[4]		Temperature change (relative to 1850–1900)[5, 6]				
			2011–2050	2011–2100	2050	2100	2100 Temperature change (°C)[7]	Likelihood of staying below temperature level over the 21st century[8]			
								1.5 °C	2.0 °C	3.0 °C	4.0 °C
< 430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq										
450 (430–480)	Total range[1, 10]	RCP2.6	550–1300	630–1180	−72 to −41	−118 to −78	1.5–1.7 (1.0–2.8)	More unlikely than likely	Likely	Likely	Likely
500 (480–530)	No overshoot of 530 ppm CO_2eq		860–1180	960–1430	−57 to −42	−107 to −73	1.7–1.9 (1.2–2.9)	Unlikely	More likely than not		
	Overshoot of 530 ppm CO_2eq		1130–1530	990–1550	−55 to −25	−114 to −90	1.8–2.0 (1.2–3.3)		About as likely as not		
550 (530–580)	No overshoot of 580 ppm CO_2eq		1070–1460	1240–2240	−47 to −19	−81 to −59	2.0–2.2 (1.4–3.6)		More unlikely than likely[12]		
	Overshoot of 580 ppm CO_2eq		1420–1750	1170–2100	−16 to 7	−183 to −86	2.1–2.3 (1.4–3.6)				
(580–650)	Total range	RCP4.5	1260–1640	1870–2440	−38 to 24	−134 to −50	2.3–2.6 (1.5–4.2)				
(650–720)	Total range		1310–1750	2570–3340	−11 to 17	−54 to −21	2.6–2.9 (1.8–4.5)		Unlikely	More likely than not	
(720–1000)	Total range	RCP6.0	1570–1940	3620–4990	18 to 54	−7 to 72	3.1–3.7 (2.1–5.8)	Unlikely[11]		More unlikely than likely	
>1000	Total range	RCP8.5	1840–2310	5350–7010	52 to 95	74 to 178	4.1–4.8 (2.8–7.8)		Unlikely[26]	Unlikely	More unlikely than likely

The end objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize greenhouse gas concentrations in the atmosphere. To achieve this, the annual global average surface temperature should be limited to below 2°C relative to the pre-industrial era [4].

European Union Studies [5]have indicated that buildings and services are responsible for 16% of CO2eq gas emissions and the roadmap for 2050 is aimed at reducing these emissions by 37%-53% by 2030, and by 88%-91% by 2050 [5].In Australia, residential buildings account for 13% of greenhouse gas emissions (GHG)[6].

In 2009, the European Union (EU) adopted a range of measuresknown as the Climate and Energy Package,whichlegislated on energy and climate change and aimed at reducing greenhouse gas emissions by 20% by 2020, compared to 1990 levels established by the Kyoto Protocol.

According to Directive 2010/31/EUon the energy performance of buildings [7], buildings account for 40% of total energy consumption in the European Union. One of the measures proposed by the Directive is to reduce energy consumption by 20% and to ensure that new buildings owned and occupied by public authorities are nearly zero-energy (nZEB) after 31 December 2018 and all new buildings are nearly zero-energy by 31 December 2020.

In order to develop an energy efficiency calculation methodology, the European Union issued guidelines in Directive 2002/91/CE [7], and later in the annexe of Directive 2010/31/EU [8], which defined the general framework for calculating the energy performance of buildings. These Directives, together with the development policies of each nation, are aimed at establishing the thermal energy consumption in the use or operational phase of buildings. Energy performance certification mainly promotes the enhancement of the energy efficiency of buildings based on energy labelling. García [9] takes a critical view, stating that these methodologies do not take into account Life-Cycle Assessment(LCA) and, therefore, the embodied energy in the manufacture of the building materials. This can lead to a scenario in which an energy-efficient building with high embodied energy achieves a high energy performance rating, while a building built with low embodied energy materials, but with high energy consumption, has a poor energy performance rating. However, if the two parameters were taken into account during the useful lifespan of the building, the second building could possibly prove to be more efficient than the first in terms of total energy consumption.

All these measures are focused on energy efficiency with the aim of reducing the consumption of and dependence on imported energy, but we must not forget that this factor has a direct impact on CO2 emissions. It should be noted that not every country has the same energy policy and this directly affects CO2 emissions - the so-called carbonation index or carbon intensity of energy (defined as CO2 emissions per unit of consumed energy,CO2i/Ei)[9]. Another important factor is energy intensity, which can be used as an indicator to measure energy efficiency (defined as units of energy per unit of GDP, Ei/PIBi) [10].

Countries that depend on fossil fuels obviously cause more pollution than those that rely to a greater extent on renewable sources of energy, but it is not so clear that these countries pollute more when compared on the basis of energy intensity, economic rent and population. For further information, see the report by VicentAlcántaraand Emilio Padilla [11] (Table 2).

Nejat P. et al [12]provides a review about the status and current trends of energy consumption, CO2 emissions, and energy policies in the residential sector.It is precisely on this area that our article is focused –the creation of a simplified EPC model based on CO2 emissions. Our study focuses on newly-built, detached, single-family houses, but can be extended to multi-family properties, semi-detached houses and tertiary sector buildings. The methodology is based on using existing energy performance rating scales approved by Spain, as well as a constructive methodology using the CO2 emissions rating system devised by Castellano J.[13].

Table 2: Decomposition of 2001 European emissions, following the Kaya identity [11].

	Kaya identity factors						
	CO2	Carbonation index CO2/E	Energy Intensity E/GDP	GDP per capita GDP/P	Population P	Emission intensity of GDP CO2/GDP	Emissions per capita CO2/P
Austria	66.63	2.17	154.32	24.49	8.13	334.71	8.20
Belgium	119.6	2.03	230.42	24.91	10.28	467.10	11.63
Denmark	50.45	2.55	143.25	25.76	5.36	365.37	9.41
Finland	60.23	1.78	271.21	24.03	5.19	483.00	11.61
France	384.85	1.45	190.44	22.89	60.91	275.97	6.32
Germany	850.16	2.42	182.67	23.34	82.34	442.32	10.32
Greece	90.15	3.14	173.70	15.08	10.96	545.60	8.23
Ireland	43.11	2.88	136.08	28.59	3.85	391.62	11.20
Italy	425.27	2.47	133.60	22.22	57.93	330.33	7.34
Luxemburg	8.41	2.20	199.27	43.68	0.44	437.57	19.11
The Netherlands	177.48	2.30	193.48	24.88	16.04	444.76	11.06
Portugal	59.05	2.39	148.31	16.58	10.06	354.12	5.87
Spain	285.6	2.24	172.25	18.36	40.27	386.21	7.09
Sweden	48.05	0.94	236.84	24.22	8.9	222.92	5.40
United Kingdom	540.84	2.3	181.80	22.00	58.79	418.13	9.2
European Union	3,209.88	2.15	177.33	22.22	379.44	380.74	8.46
Coefficient of variation x 100		23.29	20.82	15.56		20.43	34.65

2.Energy efficiency of buildings in Europe

To understand how energy performance calculation methodologies and certificates have developed in Europe, it is essential to review the evolution of the legislation governing them.

The evolution of energy efficiency monitoring in Europe has been determined in the first stage by the individual development of energy-saving measures and their communication in the form of energy labelsby some Member States. These were later adopted with corresponding adjustments to the European Directives.

The first Member State to introduce a calculation system to measure energy efficiency rates in buildings was the United Kingdom (UK), where the so-called energy ratings were established in 1995 by means of the Standard Assessment Procedure (SAP). This system gradually evolved to the currently-used system, which dates back to 2005,andKelly et al. presented how to identify characteristics which are working well on existing policy, but also what factors may lead to larger and more rapid improvement of the building stock in UK [14].The first country to use energy-labelling schemes was Denmark in 1997 at the same time as a centralized database was developed, serving as a model for the creation of EPBDs. For further information on Danish energy-labelling schemes, see [15][16].

On 15 January 1985, the European Economic Community (EEC) invited Member States to pursue the development of integrated energy-saving policies. Consequently, on29 October 1991, Council Decision 91/565/EECwas passed, in which the SAVE programme (Specific Actions for Vigorous Energy Efficiency) [17], which would be the embryo of future European Union energy efficiency policies, was approved. On 13 September 1993, Council Directive 93/76/ECC [18], on the limitation of carbon dioxide emissions by enhancing energy efficiency, was passed. This Directive is one of the first documents in which a clear reference is made to policies for stabilizing and reducing CO2 emissions, while claiming that the residential and tertiary sectors accounted for 40% of the final energy consumption in the European Community, and that these sectors were expanding. The purpose of the Directive was also for Member States to limit CO2 emissions by enhancing energy efficiency through the implementation of energy-labelling schemes, billing on the basis of actual consumption, third-party financing for energy-efficiency investments in the public sector, thermal insulation of new buildings, regular inspections of boilers and energy audits of undertakings with high energy consumption.

On 29 November 2000, the Green Paper: Towards a European Strategy for theSecurity of Energy Supply was adopted by the European Commission. In this paper, an analysis is made of energy-related issues in the European Union at that time; the high dependence of Member States on external sources of energy supply, high fossil fuel consumptionand the consequent level of emissions, and failure to comply with the Kyoto Protocol obligations. A reference is also made in this paper to actions that need to be taken to address these issues. One of the proposals is the enhancement of energy efficiency in the different sectors, in particular, the residential building sector [19].

On 16 December 2002, the European Commission adopted the first Directive(2002/91/EU)toclearly establish that the energy performance of buildings should be calculated on the basis of a methodology, which could be differentiated at a regional level, and which included not only thermal insulation, but also heating and air-conditioning installations, the application of renewable energy sources and the design of the building. At the same time, it established that new buildings had to meet minimum energy performance requirements tailored to the local climate. It should be possible to recover the cost of the energy efficiency measures taken within a reasonable period of time in relation to the expected useful lifetime of the investment. The Directive also established that energy certification schemes should be carried out as well as the regular maintenance of boilers.

On a communication level, the energy performance of a building should be clearly articulated and could include a CO2 emissions indicator. This is an important aspect since it was not mandatory to communicate CO2 emissions to end-users and, therefore, the opportunity to raise user awarenesswas lost. The Directive also made a distinction between new buildings, existing buildings, and residential and non-residential buildings. As regards the energy performance certificate, this had to be made available to the prospective buyer or tenant, as the case may be. Member States were required to bring into force the laws and regulations laid down in the Directive by 4 January 2006 at the latest.

Policies and regulations established by each country are closely linked with the dependence they have regarding the use and production of energy. Data supplied by [20] indicates that EU-28Gross Inland Consumption for typologies of resourcesis the following: 34% petroleum, 23% gas, 17% solid fuels, 14% nuclear heat, 11% renewables, and 1% waste and non-renewables. It is important to keep in mind that this structure is different for each EU country. For instance, if the Oil consumptionbetween Estonia and Luxembourg is compared, it can be noticed that there is a big difference since the first case has one of 20% while the second has one of 65%. Another example is the distinct amounts of nuclear energy used in France, which lies on a 40%, andthe UK, which consumes a 10%.In order to meet the common objectives, each EU country must legislate and implement the necessary policies according to their characteristics that result on different standards.

The EU established a methodology that all countries had to follow to determine the basis of their energy performance requirements, a methodology based on the cost-optimal from reference buildings, energy efficiency measures, final assessment of the primary energy, and the calculation of the costs of energy efficiency measures. This methodology has brought different problems to each country. For instance, in the case of theNetherlands, the prime challenge this methodology brought was the diversity of the existing building stocks, which was one of the reasons that lead to the establishment of a large number (184) of reference buildings. Another example is the case of Spain, in which the different climatic zones brought the need ofheating and cooling, which complicated the obtaining of an optimum energy performance.Moreover, in Germany, the most significant parameters were the energy price and the energy price development. In addition, in Slovenia, the facilities' subsidies had a great impact on the cost-optimal solutions.All the legislations of the EU member States along with more information about the energy efficiency of buildings are available inthe energy performance of buildings concerted actions [21]. Pan and Garmston [22] introduce building energy regulations, standards and codes within the international context while exploring how the factors influence the compliance and the implications of building energy regulations and policies.

3. Energy Directives and Certificates

Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings is the recast of all existing EPBDs. This Directive, colloquially known as 20/20/20, aims to reduce greenhouse gas emissions by 20%, reduce energy consumption by 20%, and establish a 20% share of energy from renewable sources by 2020. It lays down the following requirements:

i. A methodology for calculating the energy performance of buildings and building units.
ii. The application of minimum requirements to the energy performance of new and existing buildings, building envelope renovations, and technical installations.
iii. An increase in the number of nearly zero-energy buildings.
iv. Energy performance certification and inspection reports.
v. Independent control systems for energy performance certification.

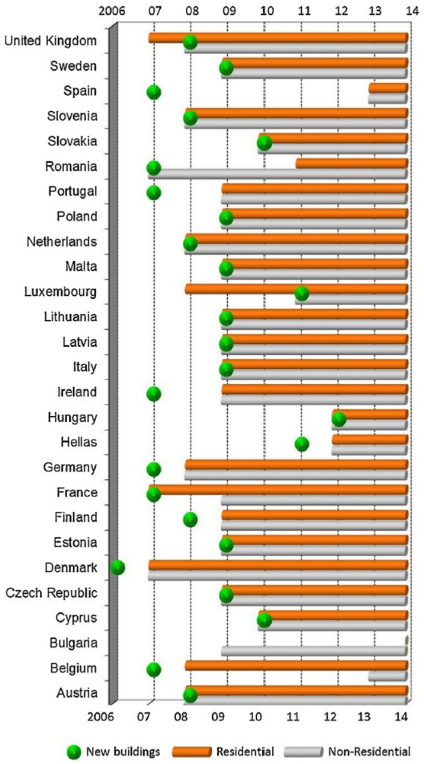
The Directive establishes a calendar for the transposition of the laws by the different Member States. Nowadays, apart from Directive 2010/31/EU, different Directives, Regulations and Guidelines exist that help to attain the previously proposed objectives. Some of these are: Directive 2012/27/EU of 25 October 2012, concerning energy performance [23], Delegated Regulation (EU) 244/2012/ of 16 January 2012 [24] and Guidelines 2012/C115/01, which accompany the former.

Current European Union debate focuses on the objectives for 2030 of a mandatory 40% CO2 emission reduction, a renewable energy target of 27% of final energy consumption in Europe as a whole, and a 30% energy efficiencytarget[25].

3.1 Energy Performance of Buildings Directives (EPBDs) in Europe and Energy Performance Certification (EPC).

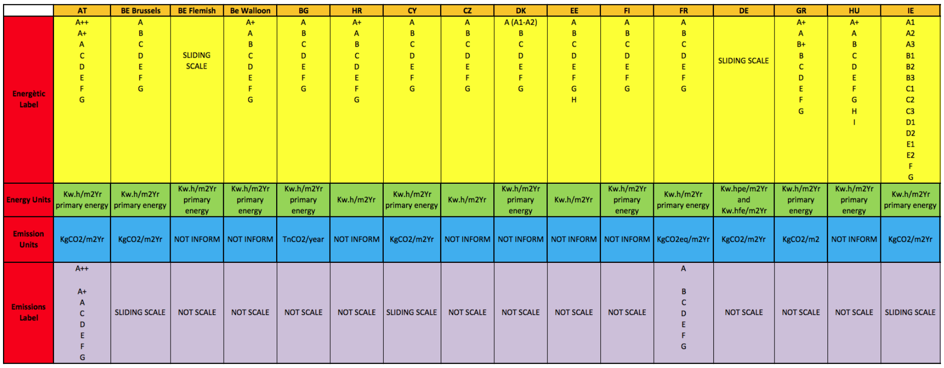
E.G.Dascalaki et al. [26]outlines the state of the art of EPCs in different European countries up to 2013, mentioning disparities in the application of the law due to delays in transposing EPBDs(fig. 1). Another problem has been the discrepancies among EU Member States in registration; some have centralized registration at a national level, others at a regional level, while others fail to have a registration system. This has resulted in the number of certificates issued among the different countries to be between 1% and 24% [27]. The percentage of dwellings pending EPC is between 80 and 90% [26]. This issue directly affects one of the Directive's objectives – comparative benchmarking carried out among the different countries, also aggravated by the variation in data of the different EPCs issued by the Member States. However, it is true that from the point of view of the management of information provided by the EPCs, States and Regions are able to carry out internal studies and apply energy efficiency enhancement policies stemming from individual studies conducted until now. Some of these studies are mentioned by Magalhaes [28], and are important to highlight due to the amount of information collection they represent[29 -43].

Fig.1 Overview of the timeline for mandatory issue of EPCs in EU-27 [21]

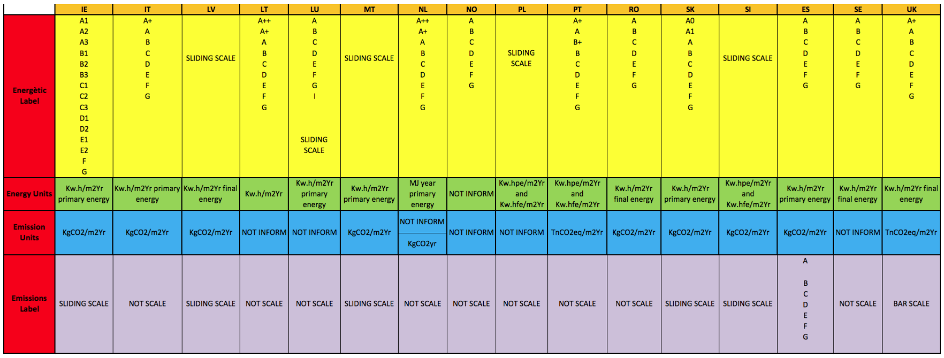


EPC certificates are highly important and essential documents, because they must inform potential buyers, tenants and users about the energy performance of buildings or building units (apartments, offices), and they permit building units or buildings as a whole to be compared. Murphy [44] presents a comprehensive assessment of the EPC in the Netherlands, and he compares the recent homeowners with an EPC to the recent homeowners without an EPC.One of the objectives underlying the creation of the EPC is to promote the demand for more energy efficient buildings or building units. Therefore, the information on the label is of utmost importance since, depending on the type of indicators and the layout, it will have an influence on the information that is provided and made public. Basically, the layout of energy labels and energy performance certificates should be based on standard EN 15217 [45], which defines the format of energy labels, the rating process, documentation for certification, reference values, efficiency indicators, symbols and abbreviations. It is important to take into account that an EPC certificate is basically made up of two parts: the energy performance certificate itself, with a 3-5 page document depending on the country, and on the other hand, an energy performance label, which is a 1-page document that highlights the most relevant, summarized data. To gain an objective insight into how each country communicates energy performance on their respective energy performance labels, a table has been drawn up(Table 3) in which the type of scale used to communicate energy efficiency, CO2 emissions and the measurement units of these two concepts can be seen.

Table 3. Table showing the information on the different energy performance labels used by EU countries.



	AT	BE Brussels	BE Flemish	Be Walloon	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE
Energètic Label	A++ A+ A C D E F G	A B C D E F G	SLIDING SCALE	A+ A B C D E F G	A B C D E F G	A+ A B C D E F G	A B C D E F G	A B C D E F G	A (A1-A2) B C D E F G	A B C D E F G H	A B C D E F G	A B C D E F G	SLIDING SCALE	A+ A B+ B C D E F G	A+ A B C D E F G H I	A1 A2 A3 B1 B2 B3 C1 C2 C3 D1 D2 E1 E2 F G
Energy Units	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.hpe/m2Yr and Kw.hfe/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy
Emission Units	KgCO2/m2Yr	KgCO2/m2Yr	NOT INFORM	NOT INFORM	TnCO2/year	NOT INFORM	KgCO2/m2Yr	NOT INFORM	NOT INFORM	NOT INFORM	NOT INFORM	KgCO2eq/m2Yr	KgCO2/m2Yr	KgCO2/m2	NOT INFORM	KgCO2/m2Yr
Emissions Label	A++ A+ A C D E F G	SLIDING SCALE	NOT SCALE	NOT SCALE	NOT SCALE	NOT SCALE	SLIDING SCALE	NOT SCALE	NOT SCALE	NOT SCALE	NOT SCALE	A B C D E F G	NOT SCALE	NOT SCALE	NOT SCALE	SLIDING SCALE



	IE	IT	LV	LT	LU	MT	NL	NO	PL	PT	RO	SK	SI	ES	SE	UK
Energètic Label	A1 A2 A3 B1 B2 B3 C1 C2 C3 D1 D2 E1 E2 F G	A+ A B C D E F G	SLIDING SCALE	A++ A+ A B C D E F G	A B C D E F G I SLIDING SCALE	SLIDING SCALE	A++ A+ A B C D E F G	A B C D E F G	SLIDING SCALE	A+ A B+ B C D E F G	A B C D E F G	A0 A1 A B C D E F G	SLIDING SCALE	A B C D E F G	A B C D E F G	A+ A B C D E F G
Energy Units	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	Kw.h/m2Yr final energy	Kw.h/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr primary energy	MJ year primary energy	NOT INFORM	Kw.hpe/m2Yr and Kw.hfe/m2Yr	Kw.hpe/m2Yr and Kw.hfe/m2Yr	Kw.h/m2Yr final energy	Kw.h/m2Yr primary energy	Kw.hpe/m2Yr and Kw.hfe/m2Yr	Kw.h/m2Yr primary energy	Kw.h/m2Yr final energy	Kw.h/m2Yr final energy
Emission Units	KgCO2/m2Yr	KgCO2/m2Yr	KgCO2/m2Yr	NOT INFORM	NOT INFORM	KgCO2/m2Yr	NOT INFORM KgCO2yr	NOT INFORM	NOT INFORM	TnCO2eq/m2Yr	KgCO2/m2Yr	KgCO2/m2Yr	KgCO2/m2Yr	KgCO2/m2Yr	NOT INFORM	TnCO2eq/m2Yr
Emissions Label	SLIDING SCALE	NOT SCALE	SLIDING SCALE	NOT SCALE	NOT SCALE	SLIDING SCALE	NOT SCALE	NOT SCALE	NOT SCALE	NOT SCALE	NOT SCALE	SLIDING SCALE	SLIDING SCALE	A B C D E F G	NOT SCALE	BAR SCALE

One of the main problems when comparing energy performance and CO2 emissions labels are the symbols used in the graphical representation. Some countries use a rating scale and others, an indicator and sliding scale. Therefore, twenty-five countries use a rating scale and six (Belgium, Germany, Latvia, Malta, Poland, Slovenia) use a sliding scale. If they are compared to each other in groups according to the representation format, differences can also be found. For instance, ten of the countries using a rating scale use an A-G scale; A being the most efficient and G being the least efficient.Following on are three countries (Austria, Lithuania, and The Netherlands) that use an A++, A+, - G scale, five countries that use an A+, A – G scale, two (Portugal and Greece) that use an A+, A, B+, B, C – G scale, and the remaining countries use their own particular scale.

As for calculation units, Kwh/m2.yr of primary energy is used by the majority, but even though they use the same unit, they cannot be compared because they have been calculated differently due to the conversion of final energy to primary energy, or vice versa, as this factor depends on the infrastructures of each country.

Specifically, in the case of emissions, only eleven countries use graphic symbols. Regarding the quantitative information about emissions, 18 out of the 31 countries provide information, but it should be taken into account that France, Portugal and the UK measure equivalent CO2, and the rest, CO2.

Making a general comparison among countries is clearly impossible as other factors exist, such as the concept of useful floor area (m2), the energy mix as a conversion factor from energy to CO2 emissions, the calculation methodology itself, etc., all of which complicate comparisons.

3.2 Energy Performance of Buildings (EPBD) and Energy Performance Certificates (EPC) in Spain.

In 2007, Royal Decree RD 47/2007 of 19 January was published. This Decree laid down the basic procedure for energy certification of new buildings. It established a mandatory energy efficiency label for all new buildings. In 2013, Royal Decree RD 235/2013 of 5 April adopted a basic procedure for energy certification of all buildings, both new and existing. This Royal Decree made it mandatory to provide buyers or users of some buildings (there are exceptions) or part thereof with an energy performance certificate. This Royal Decree rescinded and replacedRD 47/2007.This calculation methodology is applicable in the whole of Spain, but the different autonomous communities (regions) are responsible for laying down the procedures to obtain an energy label.

The main objectives are to inform the buyer or tenant by means of an A-G measurement scale (A is the most energy efficient, G the least) in order to promote the construction of more energy efficient buildings and to foment the renovation of the existing building stock.

The generic procedure for issuing the energy performance of buildings certification consists of: a) a report; a document created following a technical calculation procedure to determine the energy performance of a building, or part thereof, and potential improvements to energy efficiency, using tools recognized by the Ministry of Industry, Energy and Tourism of Spain,andb)Certification; this is the administrative procedure by which the certificate is validated and registered in the General Register of energy performance certificates of the different Autonomous Communities (Regions), and c)Energy Efficiency label; once the presented documents have been checked and validated, the relevant body of the Autonomous Community (Region) issues the energy efficiency label to the owner of the building. This energy label is valid for 10 years (Fig.2 andFig. 3).

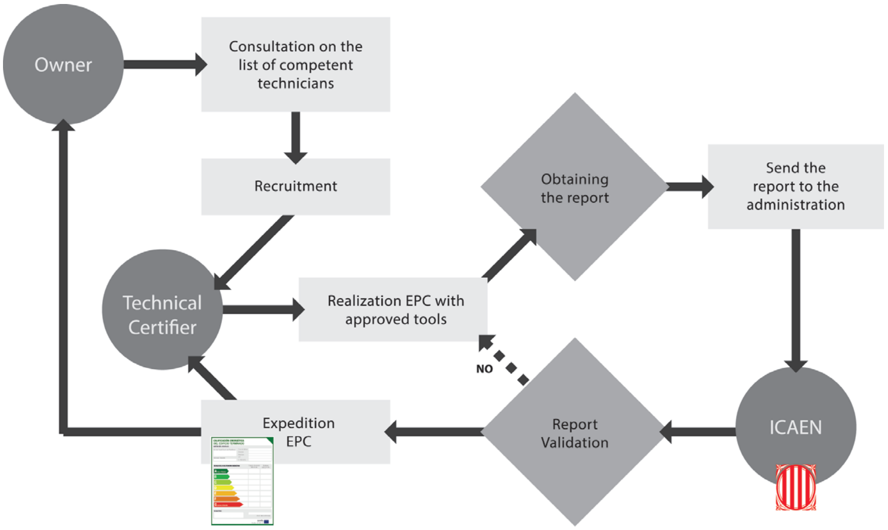
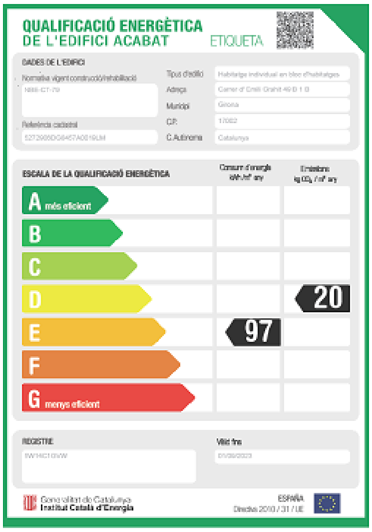


Fig.2 Procedure for energy performance of buildings certification.

Fig.3 Energy label.



QUALIFICACIÓ ENERGÈTICA
DE L'EDIFICI ACABAT
ETIQUETA

DADES DE L'EDIFICI
Normativa vigent construcció/rehabilitació
Referència cadastral
Tipus d'edifici: Habitatge individual en bloc d'habitatges
Adreça
Municipi: Girona
C.P.
C.Autònoma: Catalunya

ESCALA DE LA QUALIFICACIÓ ENERGÈTICA	Consum d'energia kWh/m² any	Emissions kg CO_2 / m² any
A més eficient		
B		
C		
D		20
E	97	
F		
G menys eficient		

REGISTRE
Vàlid fins

Generalitat de Catalunya
Institut Català d'Energia
ESPAÑA
Directiva 2010 / 31 / UE

As can be seen in Fig.3, the label provides information about the CO2 emissions (KgCO2/m2.year) and primary energy consumption (kwh/ m2.year)of the building or part thereof, depending on the object of inspection (building, apartment, premises, etc). This rating depends on the demand and energy consumption of the various services that consume energy (heating, cooling, sanitary hot water and lighting for tertiary buildings). Different calculation systems are used to obtain the emissions and primary energy consumed, but the reference software is CALENER (Table4).

Table 4 Tools used to obtain the emissions

	Opción Simplificada	*Opción General*
Edificios Nuevos	CES, C2, CERMA	CALENER VyP, CALENER GT
Edificios Existentes	CE3X, CE3	CALENER VyP, CALENER GT

To obtain the final results, the calculated values are compared with a series of reference values that vary according to the local climate, and with a reference building of the same shape, which abides by building energy regulations, depending on whether it is a new or existing building, or a residential or non-residential one.

In Spain, there are currently 25,208,622 housing units, of which approximately 55% (13,759,266) were built before 1980, and almost 21% (5,226,133) are more than 50 years old. There are currently 723,043 new housing units lying empty [46]. The report published by the Ministry of Industry, Energy and Tourism on 1 June 2014 confirms the number of energy performance certificates (EPCs) issued to date. According to this report, only659,499 housing units have been issued certificates, representing 2.6% of the total residential building stock(Table5).

	Dateupdate	New	Existing
Andalucia	31/03/2014	609	88,308
Aragó	07/04/2014		32
Asturias	01/04/2014	17	3,993
Baleares	23/04/2014	188	18,017
Canarias	11/11/2013	181	32,172
Catalunya	01/04/2014	5,53	195,089
C. León	24/04/2014	72	27,7
C. Mancha	31/03/2014	17	10,507
Extremadura	17/01/2014	3,015	1,072
Galicia	31/03/2014	65	399
Murcia	10/04/2014	154	16,233
Navarra	31/12/2013	747	5,926
Pais Vasco	27/05/2014	125	17,085
Rioja	31/03/2014	283	5,388
Valencia	03/04/2014	2,951	128,888
Madrid	01/04/2014	176	91,368
Cantabria	08/05/2014	10	3,182
TOTAL		14,140	645,359

Table 5 Energy Performance Certificates (EPCs) by Autonomous Community[40]

Table 6 and Figure 4 show the energy rating in CO2 emissions by Autonomous Community and by the number of certificates issued to new buildings. It can be calculated that 39% of the certificates correspond to E, F and G ratings.

Table 6 EPCs issued to new buildings based on CO2emissions[40].

	A	B	C	D	E	F	G	
ANDALUCIA	15	43	122	337	73	8	11	609
ARAGÓN	0	0	0	0	0	0	0	
ASTURIAS	0	4	5	1	7	0	0	17
BALEARES	1	4	6	28	63	31	55	188
CANARIAS	1	4	12	42	55	16	51	181
CATALUNYA	526	823	988	1903	1,29	0	0	5,53
C. LEÓN	20	9	13	18	11	1	0	72
C. MANCHA	2	3	8	3	1	0	0	17
EXTREMADURA	24	87	211	560	2,133	0	0	3,015
GALICIA	12	13	10	15	15	0	0	65
MURCIA	0	1	4	26	77	25	21	154
NAVARRA	114	140	137	179	136	20	21	747
PAIS VASCO	3	7	50	57	7	1	0	125
RIOJA	1	10	29	93	120	16	14	283
VALENCIA	8	11	69	1,598	1,265	0	0	2,951
MADRID	2	37	79	36	18	0	4	176
CANTABRIA	0	0	1	1	4	4	0	10
TOTALS	729	**1,196**	**1,744**	**4,897**	**5,275**	**122**	**177**	**14,140**

Fig.4 Ratings of new buildings based on CO2emissions [40].

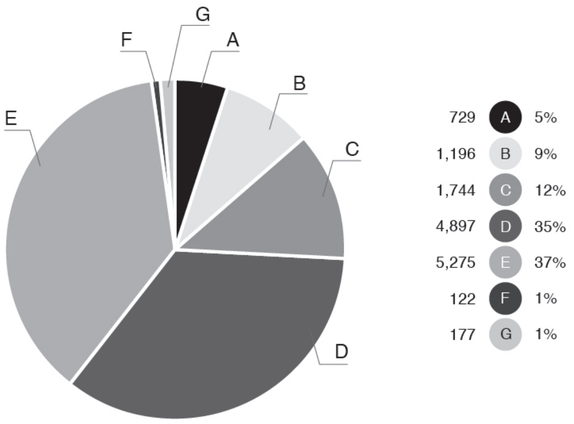
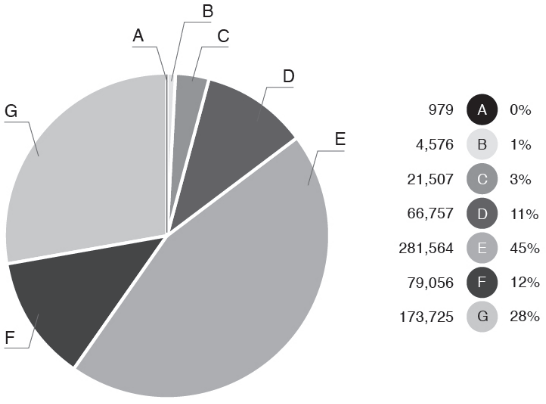


Table 7 and Figure 5 show the energy rating based on CO2 emissions by Autonomous Community and by the number of certificates issued to existing buildings. These data show that 85% of the certificates correspond to E,F and G ratings.

Table 7 EPCs in existing buildings based on CO2 emissions[40].

	A	B	C	D	E	F	G	
ANDALUCIA	98	525	2,481	7,484	41,222	12,345	24,153	88,308
ARAGÓN	0	0	2	8	17	3	2	32
ASTURIAS	7	30	164	647	1,695	466	984	3,993
BALEARES	36	119	507	1,414	6,412	2,216	7,313	18,017
CANARIAS	70	294	957	966	2,999	2,979	23,907	32,172
CATALUNYA	280	1,366	8,123	22,892	86,985	26,259	49,184	195,089
C. LEÓN	205	202	1,738	5,542	13,903	2,405	3,705	27,700
C. MANCHA	17	35	295	1,812	5,487	1,043	1,818	10,507
EXTREMADURA	0	4	50	121	565	151	181	1,072
GALICIA	1	4	19	43	161	48	123	399
MURCIA	8	21	273	828	6,726	2,727	5,65	16,233
NAVARRA	14	68	418	1,424	2,526	660	816	5,926
PAIS VASCO	NO INFORMATION							
RIOJA	15	32	259	1,040	3,254	398	390	5,388
VALENCIA	54	1,19	2,131	8,27	61,813	16,262	39,168	128,888
MADRID	155	675	3,942	13,702	46,306	10,729	15,859	91,368
CANTABRIA	19	11	148	564	1,493	365	472	3,072
TOTALS	979	**4,576**	**21,507**	**66,757**	**281,564**	**79,056**	**173,725**	**628,164**

Fig.5 Rating of existing buildings based on CO2 emissions[40].



4. Simplified Energy Performance of Building Certification Model

Spain is one of the EU countries, along with Austria, Belgium (Brussels), Cyprus, France, Ireland, Latvia, Malta, Slovakia and Slovenia, whose energy performance certificates have a CO2 emissions scale and indicate, at the same time, the number of emissions. This group of nation is followed by seven other countries whose energy certificates only indicate the number of emissions. The remaining countries provide no information on emissions (Table 3). This is a highly important aspect, both from a scientific and informative point of view, when developing and dealing with technology and policies to mitigate GHGs.

The scale model goes from A (fewer emissions) to G(more emissions) in line with the calculation methodology provided by the EPC in Spain. This methodology will permit the building's emissions rate to be calculated simply in order to facilitate the simulation of building emissions in phases prior to construction.

Spain has created various computer programs so as to calculate the demand of energy in a building and the obtaining of EPC. These programs are classified in two types, the reference type (LIDER-CALENER) and simplified type (Cermis, CE3X, CE3). In each type, the programs are classified in new or already-existing buildings. LIDER and CALENER are the reference softwares used as a guide for new programs to be created.Thus, the results obtained byothercomputer programswill not be better than LIDER andCALENER.
However, on the other hand,the data displayed fromthe differentcomputer programsis introduced and showed in distinct ways. For instance, when usingLIDER-CALENER, itis necessaryto enterthe dataof the development of agraphical modelof the building(fig.8),something thatCERMAdoes not require it.Furthermore, in obtaining data, CERMA providesthepercentages ofheat lossestothe different componentsof the buildingsuch asthe roofs,floors, windows, exterior walls, and ventilations, whileLIDER-CALENER does not.

4.1 Process description

It is based on an emissions rate scale in KgCO2/m2 provided by the authorized energy simulation program CALENER VYP [47]for single-family, stand-alone properties. This scale(fig.6) varies according to climate zone. In Spain, there are 12 climate zones divided in terms of climate severity in winter and summer. The letter indicates climate severity in winter and the number, climate severity in summer. To develop the research, we created a model in which the construction system and the climate zone where the building was located were defined. The C2 climate zone [48]was chosen, as it implied heating demand in winter and cooling demand in summer, thus making parameter adjustment more difficult than in the case of study areas with only one energy demand.

Fig.6 General scale for houses in C2climate zone.

The methodology developed by Castellano et al [13] begins with the presentation of the data from the construction systems of the building studied. All of the data of the construction systems is compared with a reference building which, together with the corresponding energy simulations in the base of the CALENER program, provide an alphanumerical scale from A to G. The energy simulation with the CERMA program also provides % values of CO2 for each of the construction systems (Fig.7). Generally, the aim is to define a study building (Fig.8) which, with the CALENER energy simulation program, can have an A classification in addition to a building classification, and whose emission data can be gathered. As the building studied is subjected to an energy simulation by the CERMA program, the emission percentagesof the building components are obtained. The combination of the general scale obtained with CALENER and the percentages for the different components obtained with CERMA allow us to obtain the different scales for each of the construction systems (Fig.9).

Fig.7 General structure of the proposed methodology[12].

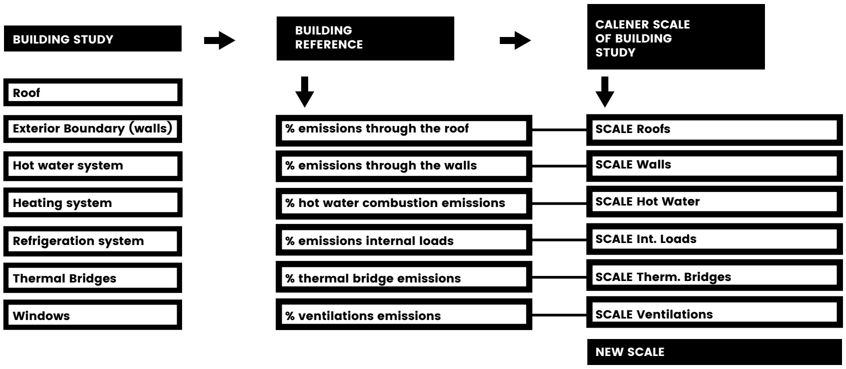


Fig.8 Different perspectives of the reference building.

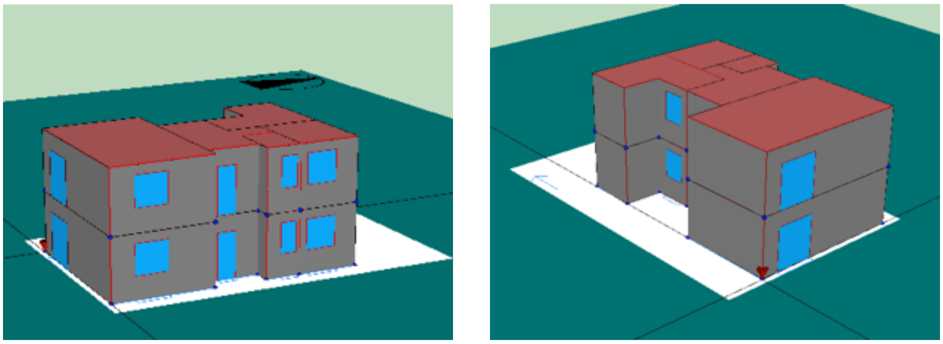
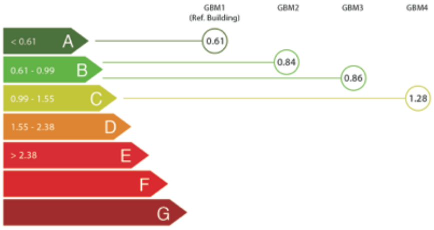


Fig.9 Roof classification for the case study

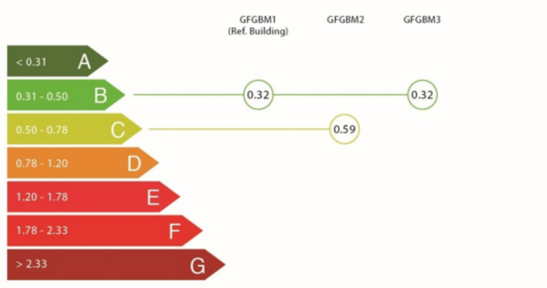


This methodology is used to obtain the scale of the different construction systems that make up the building envelope: outer walls, windows (openings), roofs, and others. Table 8 shows the list of analysed construction elements. Figures 10,11 and 12, show the ratings for the different construction elements.

Fig.10 External wall rating

Fig.11 Window rating

Fig.12 Ground Foundation rating



With this combination of construction systems, different types of finishes are generated in a detached,single-family house, known as study buildings, creating a total of 18 combinations, which are regarded as 18 different housing types. However, it must be taken into account that emissions vary depending on ventilation (air replacement), heat generated by people, known as internal thermal loads, and the domestic hot water production system. To cater for these factors, their value is set as a working hypothesis, mentioned below. These hypotheses are drawn from the result of applying another energy simulation tool, authorized by the Spanish Ministry of Energy, to the reference building: CERMA. As a result, it can be concluded that energy loss caused by air replacement rates represents 23.96%, through internal heat loads, 6.75%, and through emissions produced directly from domestic hot water production,10.16%. The other factor to bear in mind is heat loss due to thermal bridging. In this case, three hypotheses will be formulated: a) thermal bridging that represents 18.91 % of energy loss,b)not having thermal bridges, representing 0% of energy loss, and c)a mixed solution in which the proposed construction solutions do not solve the problem. In this case, we have a working hypothesis of 9.46% of energy loss. In order to obtain the final rating, the respective emission rates are added together giving a result that can be used to indicate the general scale of each housing unit and its CO2 emissions. This is called first iteration.

- T.Emissions=walls + roofs + windows + GroundFoundation + airrenovation + internalload + Hotwater + Thermal bridges
- T.Emissions=W + R + WI + GF + 23,96%·9,6KgCO2/m2 + 6,75%·9,6KgCO2/m2 + 10,16%·9,6KgCO2/m2 + TB

The case studies (detached, single-family houses) are subjected simultaneously to the energy simulation program CALENER VY, obtaining a rating for each housing unit within the general rating scale and for emissions kgCO2/m2. The same process is repeated with the CERMA program.

By observing the results obtained by applying the CERMA program to the case study buildings and by what is proposed in “first iteration”and the CALENER simulation, we can see dispersion of results and, therefore, it is necessary to find a correction factor to obtain a simplified CO2 emissions calculation methodology. The correction factor will be used to smooth out dispersion of results and standardize them, thereby obtaining a new iteration called “new methodology”

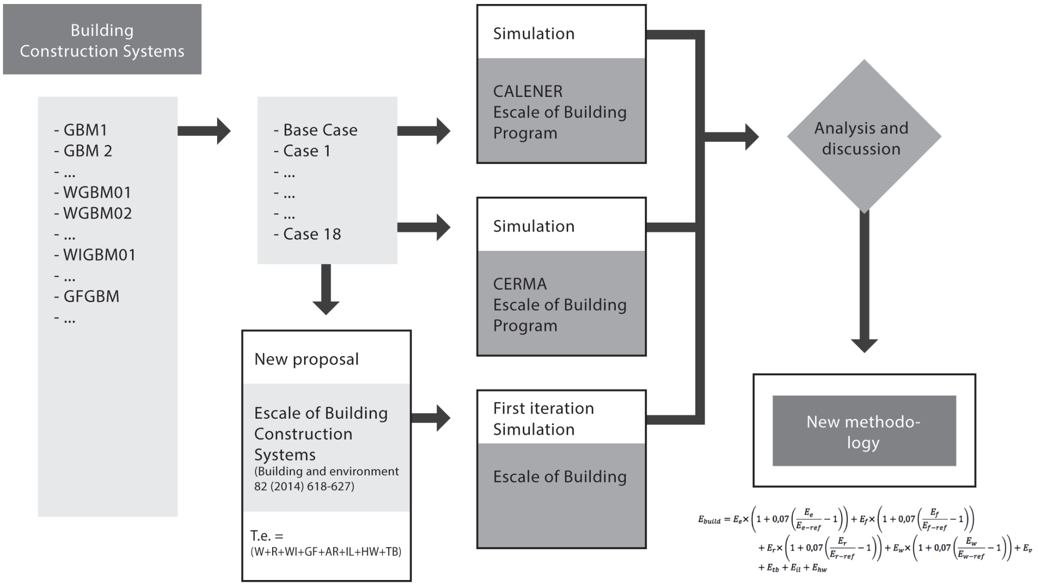
Thus, comparing calculation processesa)CALENER VIP, b) CERMA, and c) “New methodology” will enable us to see the reliability of the proposed system and the adjustments needed to adapt it to the EPC system approved by the Spanish Government. Finally, the following calculation function will be obtained (Fig.13):

$$E_{build} = E_e \times \left(1 + 0{,}07\left(\frac{E_e}{E_{e-ref}} - 1\right)\right) + E_f \times \left(1 + 0{,}07\left(\frac{E_f}{E_{f-ref}} - 1\right)\right) + E_r \times \left(1 + 0{,}07\left(\frac{E_r}{E_{r-ref}} - 1\right)\right) + E_w \times \left(1 + 0{,}07\left(\frac{E_w}{E_{w-ref}} - 1\right)\right) + E_v + E_{tb} + E_{il} + E_{hw}$$

On:

Ebuild	Total emissions building
Ee	Emissions walls
Ef	Emissions ground foundation
Er	Emissions roof
Ew	Emissions windows
Ev	Emissions air renovation
Etb	Emissions thermal bridges
Eil	Emissions internalloads
Ehw	Emissions Hot Water
Ee-ref	Emissions reference walls
Ef-ref	Emissions reference ground foundation
Er-ref	Emissions referenceroof
Ew-ref	Emissionsreferencewindows

Fig.13 General structure of the proposed methodology



$$E_{build} = E_e \times \left(1 + 0{,}07\left(\frac{E_e}{E_{e-ref}} - 1\right)\right) + E_f \times \left(1 + 0{,}07\left(\frac{E_f}{E_{f-ref}} - 1\right)\right) + E_r \times \left(1 + 0{,}07\left(\frac{E_r}{E_{r-ref}} - 1\right)\right) + E_w \times \left(1 + 0{,}07\left(\frac{E_w}{E_{w-ref}} - 1\right)\right) + E_v + E_{tb} + E_{il} + E_{hw}$$

To arrive at the final function, different statistical techniques have been applied, such as the arithmetic mean, the geometric mean, the 3rd quartile (75th percentile), the second quartile (50th percentile), the first quartile (25thpercentile), minimum values, maximum values and bounded mean values contrasting with the application of the % increase in emissions compared to the base component, the % increase according to transmittance compared to the base component, and the % increase in relation to transmittance of the base component, weighted on the percentage that it represents out of the total.

The designed function should take into account the concepts that form part of the study objective – the creation of a simplified, easily-implemented system, obtaining the greatest possible accuracy. Therefore, the option chosen from the ones analysed is first iteration plus the % increase in emissions compared to the base component, thus obtaining the "new methodology".

The results obtained in this paper confirm the achievement of a methodology that allows the performance of a faster calculation of KgCO2/m2 emissions and the level of housing efficiency, with a much higher accuracy than the two applications approved. CALENER and CERMA have adifferenceof4.64%, and the new methodology has a difference of 4.78% with CALENER and 0.15% with CERMA. However, this new methodology still cannot replace the ability to manage the data that software such as CALENER and CERMA have.

The methodology developed is static, and it can be used for any climate system. Nevertheless, is important to keep in mind that the data to apply is affected by different climatic classifications and it is been proved with the methodology developed by Castellano et al[13]. Different results will be recorded in a house with cold weather and in a house with hot weather, even if the calculation formula is the same. Despite the fact that this behaviour is followed by most of the methodologies, there are some exceptions to the pattern. For instance, a constructive system consisting of 30cmthick wall with 5cmsof insulation in a temperate climate has not the same behaviour of a cold climate, and the heat loss of the system is greater in cold weather than in the temperate one.

4.2 Case studies

This simplified methodology has been applied to eighteen cases to validate its reliability. The construction systems for the study are obtained from the BEDEC database [49], and the CALENER VYP database. These databases, and not others, have been used due to the large number of users in Spain and to their adaptation to building sector processes. The final results will be values that, properly examined, will enable us to obtain a formula (function) for a simplified calculation system of emissions in kgCO2/m2.

The reference building is a single-family 134.02 m2house (Fig.8). Figure 8 shows the two-story single-family house with its distinct façades and their facings, the type of roof that it holds (flat roof), and the number of the windows (and their respective positions) that it has. Defined in the building case study are: the building envelope, external walls, openings (windows), and the roof, and an under floor heating system and domestic hot water generated by a gas-fired condensing boiler (maximum 15 Kw) with 110% energy performance and 70% solar energy input. Air cooling is generated by an air conditioner with a nominal refrigeration capacity of 4Kw.Table 8 contains the characteristics of the material house. For example, in column 1 (enclosure) there is the name of the construction system (external wall, roof...), while in column 2 there are the transmittances of the enclosures and in column 3 there are the components of the construction systems.

Table 8
Inventory construction of the building

Enclosure	*U* (W/m2K)	Material layers
External wall	0,26	1/2 Metric Catalan solid brick pedestal (40mm<thickness<50mm) morter unventilated air chamber EPS-expanded polystyrene (0,037 W/mK) Double hollow brick partition (60 mm<thickness<90mm) Plaster skimming (1000<r<1300)
Internal wall	2,65	Plaster skimming (1000<r<1300) Double hollow brick partition (60 mm<thickness<90mm) Plaster skimming (1000<r<1300)
Internal foundation	0,76	Floor tiles Ciment or lime mortar for bricklaying and for rendering or skimming (1000<r<1250) EPS-expanded polystyrene (0,037 W/mK) Unidirectional slabs with concrete beam filling (depth 250 mm) Plaster skimming (1000<r<1300)
Ground foundation	0,6	Floor tiles Ciment or lime mortar for bricklaying and for rendering or skimming (1000<r<1250) EPS-expanded polystyrene (0,037 W/mK) Reinforced concrete (2300<r<2500) Gravel
Roof	0,22	Roof planting soil filter layer Drainage Membrane protection and root barrier waterproofing EPS-expanded polystyrene (0,037 W/mK) cellular concrete Unidirectional slabs with concrete beam filling (depth 250 mm) Plaster skimming (1000<r<1300)
window	1,8	Low emissive double glazing, 4mm thick each, and air space of 12 mm.
window frame	2,2	High medium density wood

Table 8 Inventory construction of the building

New systems, representing variations (Table 9), are introduced to the reference building to obtain,based on their combination,18 different case studies, (Table 10).In Table 9 there is a list of different construction systems classified by a code, a description, and an environmental and efficiency parameter obtained with Castellano et al. methodology [13]. Table 10 shows the various study cases classified by numbers (column 1 and 2) along with the construction systems codes obtained in Table 9..

Table 9 Inventory construction systems

Table 9

Code	*Unit*	Description	**Environmental and efficiency parameter**
		ROOFS	**A**
GBM01	m2	Flat roof garden conventional intensive, pending formation of cellular concrete, insulated with expanded polystyrene sheets, geotextile separation layer, anti-root waterproofing membrane and protection consists of two sheets one LBM (APP)-30-PE and the other LBM (APP)-40-FP, spacer layer, drainage and filter retainer with two geotextiles polystyrene substrate topsoil and 40 cm. thick.	
GBM02	m2	Inverted roof sloping concrete walkable cell separating layer, waterproofing membrane with a flexible PVC sheet not weatherproof, insulated with extruded polystyrene plates 50 mm thick, with geotextile separation layer and finished with a pavement terrazzo on supports	**B**
GBM03	m2	Inverted roof with slopes not passable aerated concrete, separating layer, waterproofing membrane with a surface density of 1.3 kg/m2 and a 1 mm thick cardboard by unregenerate synthetic rubber (butyl), insulated with extruded polystyrene plates 40 mm, with geotextile separation layer and finish layer roof boulder protection.	**B**
GBM04	m2	Not passable cover with vapor barrier / sealing with polyethylene sheet, pending formation of expanded clay poured into dry, protective layer of cement mortar, membrane protection layer of mortar, separating layer of waterproofing with a membranous surface density sheet 3.8 kg/m2 with bitumen sheet modificaco LBM (SBS)-40-FV + FP 50g/m2 to 130 g/m2 geotextile separation layer roof and finishing concrete protection layer light Expanded Clay.	**C**
		EXTERNAL WALLS	
WGBM01	m2	External wall with catalan brick (0,12 m), mortar (0,01 m), unveitilated air chamber (0,05 m), EPS-expanded polyestirene 0,037 W/mK (0,12 m),double hollow brick partition (0,06 m), plaster skimming (0,010 m).	**A**
WGBM02	m2	External wall brick (0,14 m),Mortar (0,010 m), EPS-expanded polyestirene 0,037 W/mK (0,04m), internal wall brick(0,012), plaster skimming (0,01m)	**B**
WGBM03	m2	Mortar (0,015 m), external wall brick (0,14 m), EPS-expanded polyestirene 0,037 W/mK (0,04m), cardboard panels (0,01m)	**C**
WGBM04	m2	Mortar (0,015 m), external wall brick (0,20 m), mortar (0,015m).	**D**
		WINDOWS	
WIGBM01	ut	Heigh medium density wood, low emissive double glazing, 4mm thick each, and air space of 12 mm.	**A**
WIGBM02	ut	Metalic window frame, simple glazing 6mm	**C**
WIGBM03	ut	Aluminium thermal break frame, double glazing and air space (4-9-6)	**B**
WIGBM04	ut	Normal aluminium frame, low emissive double glazing (xxxx)	**C**
		GROUND FOUNDATION	
GFGBM01	m2	Floor tiles, Ciment or lime mortar for bricklaying and for rendering or skimming (1000<r<1250),EPS-expanded polystyrene (0,037 W/mK), Reinforced concrete (2300<r<2500), Gravel	**A**
GFGBM02	m2	Floor tiles, Ciment or lime mortar for bricklaying and for rendering or skimming (1000<r<1250),concrete (d 1600), Gravel	**C**
GFGBM03	m2	Floor tiles, Ciment or lime mortar for bricklaying and for rendering or skimming (1000<r<1250),Unidirectional slabs with concrete beam filling (depth 250 mm), veitilated air chamber (0,50 m), gravel	**A**
		HEATING SYSTEMS	
HSGBM01	ut	Natural Gas condensation boiler with radiating floor system, with solar power supply of 70%, rated capacity 99%	**UNCLASSIFIED**
HSGBM02	ut	Heat pump, for heating (14kw) and cooling (12kw)	**UNCLASSIFIED**
		HEAT WATER	
HWGBM01	ut	Natural Gas condensation boiler with solar power supply of 70% , rated capacity 99%	**UNCLASSIFIED**
HWGBM02	ut	Natural Gas condensation boiler with solar power supply of 70% , rated capacity 90%	**UNCLASSIFIED**
		REFRIGERATION	
COGBM01	ut	Air-air system with nominal refrigeration capacity of 4 Kw	**UNCLASSIFIED**

Table 10 Case studies

CASE NOMBER	CASE NAME	WALLS	GROUND FOUNDATION	ROOFS	WINDOWS	HEATING SYSTEM	HEATING WATER	REFRIGERATION
1	base case	WGBM01	GFGBM01	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
2	case 1	WGBM01	GFGBM01	GBM02	WIGBM01	HSGBM01	HWGBM01	COGBM01
3	case 2	WGBM01	GFGBM01	GBM03	WIGBM01	HSGBM01	HWGBM01	COGBM01
4	case 3	WGBM01	GFGBM01	GBM04	WIGBM01	HSGBM01	HWGBM01	COGBM01
5	case 4	WGBM01	GFGBM02	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
6	case 5	WGBM01	GFGBM03	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
7	case 6	WGBM02	GFGBM01	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
8	case 7	WGBM03	GFGBM01	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
9	case 8	WGBM04	GFGBM01	GBM01	WIGBM01	HSGBM01	HWGBM01	COGBM01
10	case 9	WGBM01	GFGBM01	GBM01	WIGBM02	HSGBM01	HWGBM01	COGBM01
11	case 10	WGBM01	GFGBM01	GBM01	WIGBM03	HSGBM01	HWGBM01	COGBM01
12	case 11	WGBM01	GFGBM01	GBM01	WIGBM04	HSGBM01	HWGBM01	COGBM01
13	case 12	WGBM04	GFGBM02	GBM04	WIGBM02	HSGBM02	HWGBM02	HSGBM02
14	case 13	WGBM02	GFGBM03	GBM04	WIGBM01	HSGBM01	HWGBM01	COGBM01
15	case 14	WGBM02	GFGBM03	GBM03	WIGBM03	HSGBM02	HWGBM02	HSGBM02
16	case 15	WGBM04	GFGBM02	GBM01	WIGBM02	HSGBM01	HWGBM01	COGBM01
17	case 16	WGBM03	GFGBM03	GBM01	WIGBM01	HSGBM02	HWGBM02	HSGBM02
18	case 17	WGBM03	GFGBM02	GBM02	WIGBM03	HSGBM01	HWGBM01	COGBM01

4.3 Results and discussion

The first results obtained are emissions and rating according to the three initially proposed calculation processes: CALENER, CERMA,and”FIRST ITERATION”, by means of which we obtain emissions in kgCO2/m2 and the efficiency rating of the different case study building (A-G). Table 11 shows the first results organized by trial numbers (column 1 and 2),the results of the different methodologies in KgCO2/m2 (columns 3-5), and the results in homologate EPC scale classification (columns 6-9).

Table 11 Calculations based on different methodologies

Table 11

CASE NOMBER	CASE NAME	EMISSIONS Kg/CO2 * m2 CALENER	EMISSIONS Kg/CO2 * m2 CERMA	EMISSIONS Kg/CO2 * m2 FIRST ITERATION	EPC BUILDING CLASSIFICACTION CALENER	EPC BUILDING CLASSIFICACTION CERMA	EPC BUILDING CLASSIFICACTION FIRST ITERATION
1	base case	9,60	9,94	9,94	A	B	B
2	case 1	9,80	10,18	10,14	B	B	B
3	case 2	9,90	10,23	10,17	B	B	B
4	case 3	10,40	10,75	10,60	B	B	B
5	case 4	9,50	9,98	10,21	A	B	B
6	case 5	9,50	9,70	9,94	A	B	B
7	case 6	12,60	12,47	12,41	B	B	B
8	case 7	13,30	13,17	13,05	B	B	B
9	case 8	17,50	17,17	16,82	C	C	C
10	case 9	14,10	12,46	11,10	B	B	B
11	case 10	11,00	9,92	9,90	B	B	B
12	case 11	9,80	8,86	9,61	B	A	B
13	case 12	25,00	22,60	18,91	D	C	C
14	case 13	14,00	12,30	13,07	B	B	B
15	case 14	16,80	15,20	12,60	C	B	B
16	case 15	22,30	20,50	18,25	C	C	C
17	case 16	16,20	14,30	13,05	C	B	B
18	case 17	13,70	13,90	13,48	B	B	B

In Table 12, the difference between the applied processes can be seen, both in emission rates and in efficiency parameters according to their EPC classification (Table 12). Table 12 is shows in column 3 the result of our first iteration,in column 4 and 5 the numeric differences, and in the last columns, the same process with the EPC classification.

Table 12. Differences between methodologies

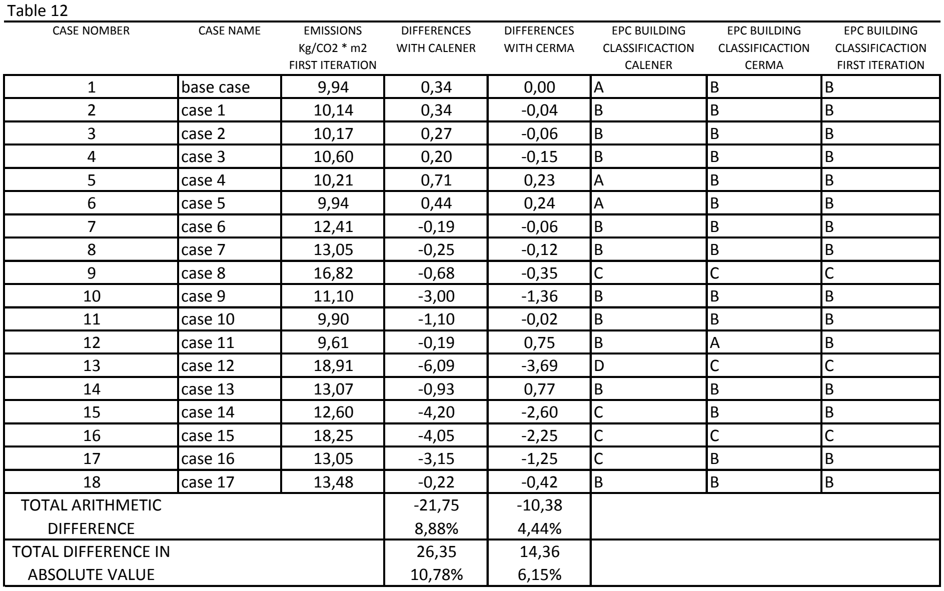


Table 12

CASE NOMBER	CASE NAME	EMISSIONS Kg/CO2 * m2 FIRST ITERATION	DIFFERENCES WITH CALENER	DIFFERENCES WITH CERMA	EPC BUILDING CLASSIFICACTION CALENER	EPC BUILDING CLASSIFICACTION CERMA	EPC BUILDING CLASSIFICACTION FIRST ITERATION
1	base case	9,94	0,34	0,00	A	B	B
2	case 1	10,14	0,34	-0,04	B	B	B
3	case 2	10,17	0,27	-0,06	B	B	B
4	case 3	10,60	0,20	-0,15	B	B	B
5	case 4	10,21	0,71	0,23	A	B	B
6	case 5	9,94	0,44	0,24	A	B	B
7	case 6	12,41	-0,19	-0,06	B	B	B
8	case 7	13,05	-0,25	-0,12	B	B	B
9	case 8	16,82	-0,68	-0,35	C	C	C
10	case 9	11,10	-3,00	-1,36	B	B	B
11	case 10	9,90	-1,10	-0,02	B	B	B
12	case 11	9,61	-0,19	0,75	B	A	B
13	case 12	18,91	-6,09	-3,69	D	C	C
14	case 13	13,07	-0,93	0,77	B	B	B
15	case 14	12,60	-4,20	-2,60	C	B	B
16	case 15	18,25	-4,05	-2,25	C	C	C
17	case 16	13,05	-3,15	-1,25	C	B	B
18	case 17	13,48	-0,22	-0,42	B	B	B
TOTAL ARITHMETIC DIFFERENCE			-21,75 8,88%	-10,38 4,44%			
TOTAL DIFFERENCE IN ABSOLUTE VALUE			26,35 10,78%	14,36 6,15%			

In Table 13, we can see the differences between the applied homologated methodologies and our final simplified methodology.Table 13 depicts in column 3 the result of our new proposal,while column 4 and 5 show the numeric differences, and the last columns capture the same process with the EPC classification.

Table 13 Differences between homologated methodologies and new proposal

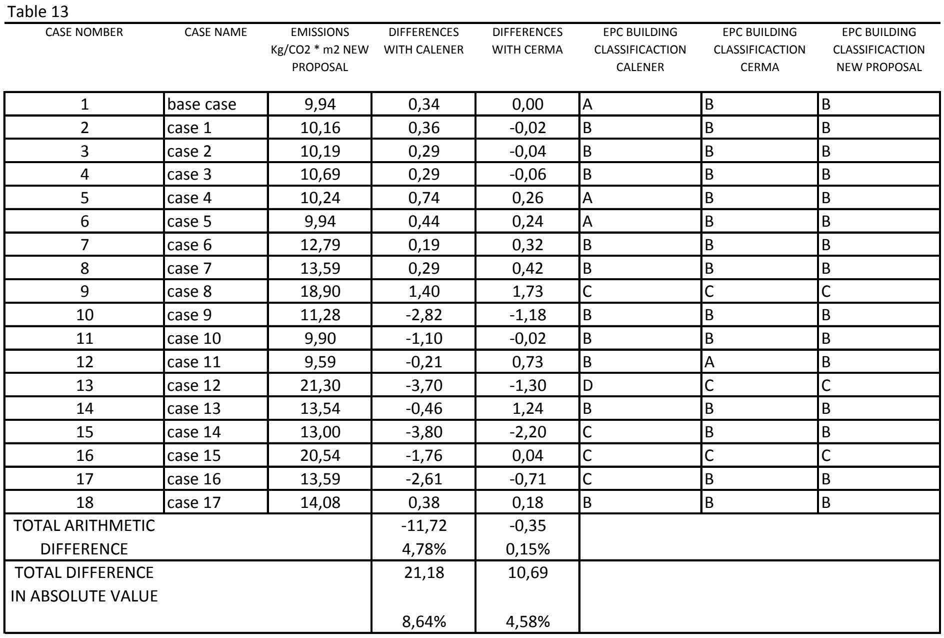
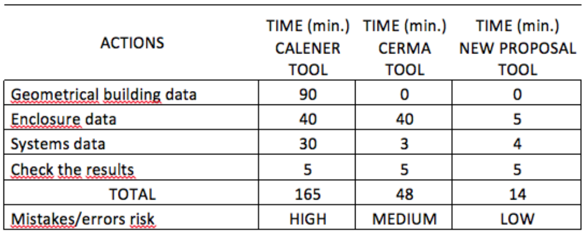


Table 13

CASE NOMBER	CASE NAME	EMISSIONS Kg/CO2 * m2 NEW PROPOSAL	DIFFERENCES WITH CALENER	DIFFERENCES WITH CERMA	EPC BUILDING CLASSIFICACTION CALENER	EPC BUILDING CLASSIFICACTION CERMA	EPC BUILDING CLASSIFICACTION NEW PROPOSAL
1	base case	9,94	0,34	0,00	A	B	B
2	case 1	10,16	0,36	-0,02	B	B	B
3	case 2	10,19	0,29	-0,04	B	B	B
4	case 3	10,69	0,29	-0,06	B	B	B
5	case 4	10,24	0,74	0,26	A	B	B
6	case 5	9,94	0,44	0,24	A	B	B
7	case 6	12,79	0,19	0,32	B	B	B
8	case 7	13,59	0,29	0,42	B	B	B
9	case 8	18,90	1,40	1,73	C	C	C
10	case 9	11,28	-2,82	-1,18	B	B	B
11	case 10	9,90	-1,10	-0,02	B	B	B
12	case 11	9,59	-0,21	0,73	B	A	B
13	case 12	21,30	-3,70	-1,30	D	C	C
14	case 13	13,54	-0,46	1,24	B	B	B
15	case 14	13,00	-3,80	-2,20	C	B	B
16	case 15	20,54	-1,76	0,04	C	C	C
17	case 16	13,59	-2,61	-0,71	C	B	B
18	case 17	14,08	0,38	0,18	B	B	B
TOTAL ARITHMETIC DIFFERENCE			-11,72 4,78%	-0,35 0,15%			
TOTAL DIFFERENCE IN ABSOLUTE VALUE			21,18 8,64%	10,69 4,58%			

Table 14 shows the actions done with the different tools used in the experiment. In the first column, there are the onescarried out to obtain the final results, and in the second, third and fourth column, the tools used in relation to the time parameter. The last row shows the level of mistakes or errors that may have been done introducing the data, and which dependon the tools used. Those areclassified in a high, medium or low level of error risk.

Table 14 Comparison between tools



ACTIONS	TIME (min.) CALENER TOOL	TIME (min.) CERMA TOOL	TIME (min.) NEW PROPOSAL TOOL
Geometrical building data	90	0	0
Enclosure data	40	40	5
Systems data	30	3	4
Check the results	5	5	5
TOTAL	165	48	14
Mistakes/errors risk	HIGH	MEDIUM	LOW

Once the different calculations have been carried out, differences in kgCO2/m2year results can be observed between the two homologated processes, CALENER and CERMA, in that the arithmetic mean is4.64% and the difference with first iteration without the first correction coefficient is 8.88% and 4.44%, respectively (table 12). At the same time, it can also be observed that the rating (EPC) only varies in the homologated CALENER system in the base case, cases4,5,11,12,14,16, decreasing in three of these cases and improving in the others. As regards the homologated CERMA system, the rating only varies in case 11 (Table 12).

Once applied coefficient, consisting of a % increase corrector of emissions compared to the base component has been applied, namely 7%.The results happen to have differences of 4.78% and 0.15% of CALENER and CERMA, respectively (Table 13).

Arithmetic data have been used rather than absolute measurements because the objective is to calculate the emissions that will be generated in the atmosphere. Therefore, by using the former, the best and worst measurements will be balanced out in the end, while with the latter, they will be accumulated.

The other proposals studied, specifically first iteration plus % increase according to transmittance in relation to the base component, weighted on the percentage that it represents out of the total, improve the final results once analysed, but complicate the resulting function. This is counterproductive when aiming to find a process that will culminate in a simplified methodology to calculate the emissions of a single-family house in its use phase.

Figure 14 shows the results. It can be seen how the simplified process betters the homologated CERMA process in some cases, and is closer in data to the homologated reference process, CALENER VYP.

Although the CALENER VYP is the reference software to obtain the EPC building classification, in Table 14 one can see that the time used by this program to obtain results is much higher than the one needed by CERMA and NEW PROPOSAL, and the probability of making mistakes is lower in NEW PROPOSAL than it is in the other two tools.

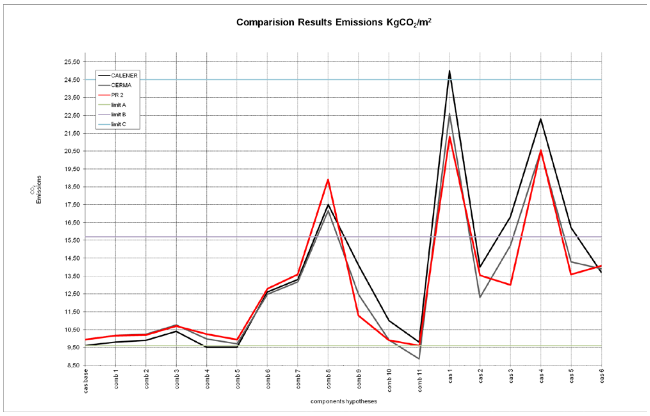


Fig.14 Emissions and EPC limits of case studies following different methodologies

5. Conclusions

Although these bases for calculating emissions and energy efficiency are the same throughout the whole of Europe, the different methodologies applied in each country give different results and make it extremely difficult to draw comparisons.The EPBD process represents an opportunity for every country and its regions to obtain information about their building stock.

In the case of Spain, EPBD is measured in kgCO2/m2 year andKw.h/m2 year. Based on emission rates, 37% of new buildings have an E rating and only 5% have an A, still leaving ample room for improvement. However, it must be taken into account that this process does not contemplate the embodied energy of the construction materials used in the building process.

The reliability of EPBD reports is another point to consider as some of the data required in the certification process depends on the criteria of the technicians [50].

Initially, the use of the EPBD as a tool to improve energy performance has been important, but increasingly its relevance as a tool to fight climate change is increasing.However, methods and applications existing in the market do not help due to their complexity to understand the characteristics to consider and the result, and long time to make calculations as well. Simplified methodology was developed in this work to make easy the calculation about CO2/m2 emissions with high accuracy. It is seen new method results compared with those methods already approved by legislation have same accuracy, making possible to rely in this method. The method iscreated and designedwith thissimplified methodology to calculate the CO2 emissions of a single-family house in the use phase of its life-cycle, enabling these emissions to be calculated for a specific number of years.Thismethodology created and validated in case studies, can be extrapolated to other types of buildings, bearing in mind certain hypotheses.

It is important to mention that discrepancies were found, when developing this methodology, among emission rates provided by CERMA, depending on whether they were given in percentages or units (kgCO2/m2), reaching 3% in some cases.
This easy-to-apply methodology can be used by building designers to take into account CO2 emissions as a key parameter in the design, enabling them to study what possibilities or factors for improvement exist, and therefore, to correct the design, which will have an impact on costs, materials, installations, etc.

One important aspect should be considered when comparing emission rates between countries; it is the conversion of primary energy to CO2 emissions that varies according to each country's source of energy production. This could lead to a paradoxical situation in which a country with high renewable energy sources and, therefore, a lower emissions factor does not necessarily havemore energy efficient buildings. Thus, the fact that a building is more or less sustainable would not be so important.

In the future, the new methodology could be improved by the introduction of a climatic-differentiation parameter.

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5. ARTÍCULO "SUSTAINABLE PROPERTY EXPERT (SPE), A METHODOLOGY AND TOOL FOR A SUSTAINABLE HOUSING ASSESSMENT"

Este capítulo presenta un estudio realizado para desarrollar una herramienta simplificada para la evaluación de la sostenibilidad de una vivienda, esta herramienta se ha desarrollado mediante el caso de estudio de un edificio plurifamiliar de viviendas y comparado con las certificaciones LEED, BREEAM.

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SUSTAINABLE PROPERTY EXPERT (SPE), A METHODOLOGY AND TOOL FOR A SUSTAINABLE HOUSING ASSESSMENT

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Abstract:

The strategies for building sustainable or green buildings currently adopted in Spain are in line with those of the European Union (EU) and other countries. These strategies are founded on two basic principles: energy efficiency and climate change. Energy efficiency attempts to serve a dual purpose, the first geopolitical – to end dependency on fossil fuel supplies from other countries – and the second to reduce energy consumption, which is directly related to the CO2 emissions into the atmosphere that are responsible for climate change. Different methods to assess the environmental impact of buildings have appeared since 1990. The various associations involved in sustainable construction in different countries currently use the methods, or rating systems, they believe to be most suitable for assessing the sustainability of buildings, the most well-known of which are LEED (USA), BREEAM (UK), CASBEE (Japan), DGNB (Germany), BEAM plus (Hong Kong) and VERDE (Spain). This study aims to develop a rating system to help potential buyers or tenants to choose a home based on its sustainability; in other words, based on the three pillars of sustainable development: economic, environmental and social. The methodology used in this study is based on existing sustainability assessment methods, and the rating system developed is intended be of general use to all countries. This method will allow potential home buyers or renters to compare the different options available to them and to see which property is most highly rated, and therefore most sustainable. The method will be tested by means of a case study of a residential property located in Tarragona in Spain, called 9centre. This will ensure that the method meets one of the basic requirements of the rating system: that it is user-friendly when helping buyers or renters to take sustainability indicators into account when looking for a home. At the same time the tool will help foment demand for Green Buildings, thus supporting global strategies to combat climate change.

Keywords: Benchmarking, LEED, BREEAM, VERDE, sustainability indicators, sustainable buildings.

1.-Introduction

The 1990 Building Research Establishment Environmental Assessment Method (BREEAM) was the first building environmental assessment rating system developed in the UK [1][2]. It was a benchmark model for methods developed in Canada, New Zealand, Norway, Singapore and Hong Kong [3]. The next rating system to be created was HK-BEAM [4] and was developed in Hong Kong in December 1996. The Leadership in Energy and Environmental Design (LEED) created by the US Green

Building Council (USGBC) for the US Department of Energy [5] was the next method to be created. The pilot version, known as Version 1, was developed in August 1998 and from there has evolved into the current Version 4 [6]. The 2002 Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is the rating system and building environmental assessment method created in Japan and administered by the Institute for Building Environment and Energy Conservation (IBEC) [7]. The "Deutsche Gesellschaft für Nachhaltiges Bauen" (DGNB), developed by the German Sustainable Building Council, appeared on the market in 2007 and aimed to become an international rating system which would be the benchmark in Europe as it was based on legislation regarding technology in the European Standards [8]. In Spain the benchmark organisation for sustainable building is the Green Building Council España (GBCe), which was recognised as an Established Council in 2011. This organisation developed VERDE, whose principle characteristic is the study of the environmental impacts created by the different criteria studied. These rating systems have been especially important in the task of establishing criteria and indicators for architects to design sustainable buildings that investors can invest in and developers can build.

BREEAM and LEED are the two building environmental assessment tools most commonly used worldwide. All of these rating systems have evolved over the years; they have been modified and have become more demanding in line with technological advances. The most recent version of LEED clearly illustrates this point as it includes credits in the materials and resources section to analyse the life cycle (environmental product declarations) of the materials used to construct the building, and it also now includes credits in the Indoor Environmental Quality category for acoustic quality [9].

Some articles about energy performance rating systems will now be reviewed to provide the reader with more information to help them attain a general overview of these methods. Lee [10] provides one of the benchmark studies on BREEAM, LEED, CASBEE, BEAM plus and the Chinese ESGB methods. His work covers the history of these rating systems, how the assessment categories and criteria etc are structured, to which type of buildings they can be applied, the methodology of the rating systems and other useful data.

Todd et al. [11] makes an important point about the methodology developed in this study: initially, these building environmental assessment tools focused on making environmental improvements in order to construct green buildings to which systems to assess social and economic aspects, in other words sustainable buildings, would be applied later. Most of these assessment tools, therefore, focus on physical and environmental aspects and give social and economic factors little importance.

Another relevant point is made by Haapio and Viitaniemi [12]: that the term "building performance" in itself is complex. This is due to the fact that the priorities of the various parties involved in the construction process are different: investors prioritise economic aspects and owners and renters prioritise health and comfort.

According to Luís Alvarez [13] 70%-80% of the European population live in cities, rising to 50% of the world population. Construction and maintenance in these cities account for 40% of all material used, 33% of energy consumed and 50% of waste emissions produced. Building sustainability rating systems place such importance on energy criteria for this reason. The weight given to this aspect ranges from 18% in BREEAM to 33% in LEED.

In a case study Schawartz and Raslan [14] compare different energy simulation tools and how they affect BREEAM and LEED. The results obtained vary according to the energy simulation tool. The principle factors responsible for this variation are how the methods deal with the surface area of a building and how the temperatures each system uses to make calculations are characterised, which together affect the energy demand of a building. The conclusion was that BREEAM got 6 out of the 27 available credits, and that LEED did not reach the minimum requirements and therefore got no points. However, if we consider the different relative importance that the two methods place on energy there was, in fact, no real difference. What does need to be stressed, though, are the differences between energy simulation tools and the effect these can have on the various sustainability rating systems.

Ferreira et al [15] make an important contribution with their work comparing the two most popular sustainable building assessment systems in Portugal, LiderA and SBTool, with BREEAM and LEED. SBTool, interestingly, bases its criteria on the three pillars of sustainability: environmental impacts, weighted at 40%, social impacts, weighted at 30%, and economic impacts, also weighted at 30%.

Seinre et al [16] contribute a study on different impact categories such as Indoor Climate Quality, Energy Water Use, Material Impact and Project Site, and place them into two groups according to whether their impact is environmental or economic, representing graphically the weight of the different impact categories in BREEAM, LEED and the method suggested by the writers of the article in the case of Estonia.

Many of these methods, including BREEAM and LEED, include a qualitative Life Cycle Assessment (LCA). Castellano et al [17] provide a table showing the different rating systems and which phases of the life cycle of a building are taken into account in each. However, if an analysis with quantitative results is required the rating system has to be different and has to be based on the analysis of the life cycle of a building. As Castellano et al [17] point out this method is based on international legislation ISO 14044:2006 and ISO 14040:2006, and with regards to the construction sector in Europe is complemented by legislation EN 15978 and EN 15804. It must be added that, at the present time, when carrying out an LCA on a product the concept of environmental footprint, regulated by the European Community in Recommendation 2013/179/UE, must be taken into account. This recommendation defines the use of common methods to measure and communicate the life cycle environmental performance of products and organisations [18].

Verbeeck and Hens [19] use LCA methodology and they confirm that the embodied energy of a building is relatively unimportant compared with the energy consumed in the use phase of a home and that the return, depending on how energy efficient the building is, can be as little as two years. Wang et al. [20] use LCA methodology to take both environmental and economic decisions on the design of a commercial building in Shanghai. Mithraratne and Vale [21] use LCA methodology as a tool for designing houses in New Zealand based on embodied energy and for calculating the energy consumed in the use phase, and for analysing Life Cycle Costs (LCC) during the useful life of the building.

Other methods used are MINERGIE [22] and PASSIVHAUS [23], but they must be applied with caution because they focus solely on reducing energy consumption and on zero or nearly-zero buildings (nZeb) [24] [25].

2.-Sustainability

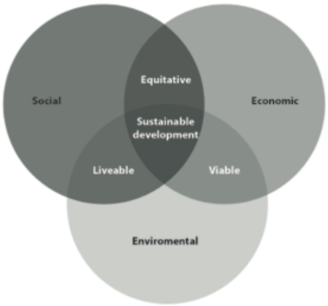
Sustainability is a new science that emerged when the United Nations World Commission on Environment and Development defined the concept of sustainable development in the Brundland report of 1987 as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [26] [27].

Komiyama and Takeuchi [28] define the concept of sustainability science of with three levels of systems: global, social and human. The global system includes planet Earth as a system comprised of the geosphere, the atmosphere, the hydrosphere and the biosphere: that which provides humans with the natural resources necessary for their survival. The global system is directly affected by human activity, of which climate change and the destruction of the ozone layer are clear examples. The social system is comprised of political-economic and industrial systems, as well as other organisational structures created by man. These systems, however, designed for mankind’s fulfilment, often create environmental problems and contribute to increasing inequality, the widening of the gap between rich and poor. Climate change, which directly affects the global system, is a clear example of one of these problems. The third system is known as the human system and is the sum of all the factors that have a bearing on the survival of the human race. According to Komiyama H, and Takeuchi [28] the human system is directly linked to the social system where living in good health and in safety is the main objective.

Sustainability, thus, can be defined as a balance between these systems – global, social and human. If we adapt this definition to the characteristics of building sustainability, this can be defined as a balance between environmental, economic and social factors where health and well-being is the main impact category in the last system (Fig.1).

A definition of sustainability that includes social, economic and environmental factors provides us with a different vision of what is known as the environment. Therefore, a distinction must be made between what is sustainable and what is simply environmentally correct.

Fig.1. Sustainable development

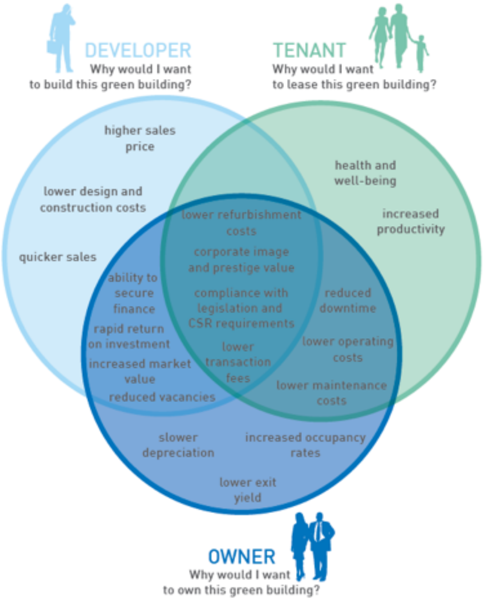


The contribution made to greenhouse gas emissions, and thus to climate change, by the building sector in developed countries is 25%-40%, and 45%-95% of these emissions occur during the use phase of the building, while the remaining percentage occurs during the construction and demolition phases. Coley D [29] has made an important contribution in his study of the effects of climate change on buildings and their users. Climate change, together with water supply, are currently the two most important environmental issues affecting humans; thus, they are two clear examples of the environmental pillar in a sustainable building. From an economic point of view, the report by the World Green Building Council [30] has shown that green buildings can save money as a result of lowered electricity and water consumption, and reduced operational and maintenance costs. According to Turner and Frankel [31] energy savings in buildings rated by LEED are 25-30% more energy efficient than the national average for buildings in the USA, while the increase in the sale price of new green buildings is 11% and in the renting price 6% [32].The social factors associated with sustainable building are health and well-being. For workplaces and homes the priority is to provide a pleasant indoor environment that improves the health, well-being and thus the quality of life of users.

3.-The Sustainable Property Expert (SPE)

Over the last few years the concepts of green buildings, energy efficiency, water consumption, climate change, energy poverty and the sick building syndrome have succeeded in raising public awareness of environmental issues and making designers see the need to construct more sustainable buildings. Existing literature on building sustainability leaves the benefits to be gained from it beyond doubt for all stakeholders - large investors (investment funds, large companies), small investors (small-scale developers) and users (families) [30]. The most important rating systems - BREEAM, LEED, CASBEE, etc. – respond to this situation, rating large buildings, particularly tertiary office buildings, schools and hospitals. The high cost of these rating systems falls to developers and large owners, as shown in fig.2.

Fig.2 Building stakeholders



This study develops a tool called Sustainable Property Expert (SPE), which provides users of residential buildings - tenants - and house buyers - small owners - with information about the sustainability of the home they want to buy, rent or possess.

Building assessment methods can be divided into two groups based on qualitative and quantitative results.

In the qualitative group we find the methods that are based on assessing factors associated with the design and construction of the building. They are structured into categories of environmental impacts and credits. A number of points, which depends on the importance given to the impacts associated with that credit, are allocated to them. This group includes such benchmark rating systems as LEED and BREEAM. Within the quantitative group we find one that is slightly different, CASBEE, which is based on the concept of eco-efficiency, defined as “the value of products and services per unit of environmental load”. The indicator developed is the relationship between the categories “Performance and Environmental Quality of the Building” and the “Associated Environmental Load”. A clear example of quantitative results can be found in the rating system used in Spain, the VERDE, which is based on GBTool. This method is comprised of a reference building with some environmental impacts, which is compared with a new building. The results obtained are a series of impacts such as climate change, potable water shortage, loss of sea life etc, together with their units of measurement [33].

The SPE assessment method draws on the approaches of the benchmark systems, in particular LEED, BREEAM and GBTool, and the result is entirely qualitative.

3.1. Methodology

Most assessment systems are based on a series of measures organised into categories or credits, depending on the rating system. These measures apply to both the project and construction phases. The aim of these rating systems is to provide project managers and developers with guidelines for the design and characteristics of a building, and also an objective way to test compliance with these building guidelines.

SPE aims to provide stakeholders in the construction sector, and in particular the housing sector, with a tool, or rating system, which can be authorised for use internationally and is aimed at those who want to buy or rent a home. This means that the method must display certain characteristics: it must employ easily-understandable language, it must be user-friendly and the results must be clear and visual. The tool must also assess building sustainability as objectively as possible, while promoting sustainability criteria when users choose a home and forcing all stakeholders in the building process – politicians, investors, builders, technicians and others – to take sustainability criteria into account.

The methodology of SPE is based on the qualitative analysis process of the life cycle, especially in the use phase of the building. It consists of assessing the economic, social and environmental impacts of the building in terms of the building itself, the site of the building and the impacts caused by its use, all of which are grouped by categories, criteria and type of impact.

The categories are groups of criteria which also create impacts, as shown in table 1. These criteria can create different impacts at the same time, and they aim to create a virtual simulation of the characteristics of the building. The tool is operated by assigning different impacts, which are classified by type - economic, environmental or social - to each set of criteria. These criteria are based on questions that the user must answer and for which, depending on the answer given, he will be awarded a number of points. A total score is given at the end of the process, and the building is rated using a five-level scale: very bad, bad, sufficient, good and very good. A rating is given for each impact type – economic, environmental and social – and for another newly-created impact, sustainability, which is the combination of the three aforementioned impacts.

Table 1. Table with categories, criteria studied and impact typology.

CATEGORIES	CRITERIA	IMPACT	POINTS
LAND USE AND ECOLOGY	1 Syte typology	ENVIRONMENTAL	10
	2 Type of plants used	ENVIRONMENTAL	
	3 Reformed Building	ENVIRONMENTAL	
TRANSPORT AND MOBILITY	4 Availability of public transport	ECONOMIC/ENVIRONMENTAL/SOCIAL	48
	5 Access to commercial services,schools and shops etc.	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	6 Storage space for bicycles	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	7 Access to public bicycle service	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	8 Shared work space	SOCIAL	
	9 Parking space for an electric car	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	10 Journey to place of work	ECONOMIC/ENVIRONMENTAL/SOCIAL	
ENERGY	11 Domestic appliance rating	ENVIRONMENTAL/ECONOMIC	94
	12 Type of interior lighting	ENVIRONMENTAL/ECONOMIC	
	13 Automatic light control	ENVIRONMENTAL/ECONOMIC	
	14 Energy performance rating of the building	ENVIRONMENTAL/ECONOMIC	
	15 Type of lighting in communal areas	ENVIRONMENTAL/ECONOMIC	
	16 Emission rating of the building or property	ENVIRONMENTAL/SOCIAL	
WATER	17 Water recycling systems	ENVIRONMENTAL/ECONOMIC	26
	18 Watering systems	ENVIRONMENTAL/ECONOMIC	
	19 Taps type	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	20 WC type	ECONOMIC/ENVIRONMENTAL/SOCIAL	
	21 Control systems for leaks	ENVIRONMENTAL/ECONOMIC	
WASTE MANAGEMENT	22 Space for domestic waste storage	ECONOMIC/ENVIRONMENTAL/SOCIAL	18
	23 Space for compost and recycling	ENVIRONMENTAL/ECONOMIC	
BUILDING MANAGEMENT	24 Type of heating	ECONOMIC	28
	25 Type of hot water production	ECONOMIC	
	26 State of building	ECONOMIC	
	27 State of property	ECONOMIC	
	28 Maintenance programme	ECONOMIC/ENVIRONMENTAL/SOCIAL	
MATERIALS AND MAINTENANCE	29 Type of exterior of walls	ENVIRONMENTAL/ECONOMIC	22
	30 Type of flooring	ENVIRONMENTAL/ECONOMIC	
	31 Type of windows	ENVIRONMENTAL/ECONOMIC	
	32 Type of roof	ENVIRONMENTAL/ECONOMIC	
HEALTH AND WELL-BEING	33 windows to the exterior	SOCIAL	49
	34 Natural light	SOCIAL	
	35 Views	SOCIAL	
	36 Private outdoor area	SOCIAL	
	37 Exterior acoustic impact	SOCIAL	
	38 Interior acoustic impact	SOCIAL	
	39 Individual control of heating and air conditioning	SOCIAL	
	40 Security systems	SOCIAL	
	41 Area for drying laundry	SOCIAL	
	42 Access to the building	SOCIAL	
FINANCIAL RISK	43 Increase in value based on environmental and social impacts	ECONOMIC	5

The need to develop a methodology that included the impacts to assess and a calculation method that would be accepted by the scientific community mean that SPE is based on LEED v4 by BD+C: New Construction and Major Renovation [6], BREEAM ES Housing [34] and SBtool [15]. Table 2 shows the weight or importance that each rating systems gives the different categories, and what this represents in terms of each impact – economic, social and environmental – relative to the overall result: sustainability.

Table 2. Weights of impact categories in the four systems

WEIGHT OF IMPACTS	**SBTool**	**LEED**	**BREEAM ES**	**SPE**
ENVIRONMENTAL	**40%**	**83%**	**45%**	**33.33%**
Climate Change	13%			
Potable Water Shortage	6%	11%	10.5%	11%
Generation of Waste			7%	7%
Energy	32%	33%	18%	34%
Transport		16%	8%	16%
Management			11.5%	10%
Use of Land and Ecology	20%	10%	9.5%	10%
Contamination			9.5%	
Materials		13%	12%	12%
Materials and Waste	29%			
ECONOMIC	**30%**	**1%**	**0%**	**33.3%**
Financial Risk and Profits for Investors				5%
Integrative Process		1%		11%
LCC Study	100%			7%
Potable Water Shortage				34%
Generation of Waste				16%
Energy				10%
Health, Well-being and Productivity for Users				5%
Materials				12%
SOCIAL	**30%**	**16%**	**14%**	**33.3%**
Health, Well-being and Productivity for Users	60%		14%	57%
Indoor Environmental Quality		16%		
Accessibility	30%			
Education	10%			
Potable Water Shortage				5%
Generation of Waste				7%
Energy				15%
Transport				16%

To create the assessment process for the sustainability of a building using SPE a point scale for each set of criteria to establish the assessment basis for each impact had to be defined. The model designed is based on a point system with fixed weights assigned to each category. This system is simple and easy to use and can be applied to buildings and residential properties located in different regions with varying conditions by simply making small adjustments to the criteria to cater for the characteristics of that region. For example, the energy criteria are based on the energy certificate that is mandatory when selling or renting a residential property in most of the European Community [24] [25].

Table 3. Points for categories and impacts

CATEGORIES	POINTS OF IMPACTS			
	ENVIRONMENTAL	ECONOMIC	SOCIAL	SUSTAINABILITY
LAND USE AND ECOLOGY	10	0	0	10
TRANSPORT AND MOBILITY	16	16	16	48
ENERGY	35	35	24	94
WATER	11	11	4	26
WASTE MANAGEMENT	7	7	4	18
BUILDING MANAGEMENT	10	15	3	28
MATERIALS AND MAINTENANCE	11	11	0	22
HEALTH AND WELL-BEING	0	0	49	49
FINANCIAL RISK	0	5	0	5
TOTAL	100	100	100	300

The point system for this assessment method is shown in table 3. The set of criteria for each category is measured on the basis of some questions which are shown in table 1, and points are given depending on the answer given. This score is firmly linked to the weight of each set of criteria within its impact. The aim is that each individual user answers these questions, and they are awarded points depending on how they answer. For example, one question could be, “Does the residents’ association have a maintenance programme for the building and do they follow it?” If they answer “yes” they are awarded three points, and this criterion affects social, economic and environmental aspects. The 43 questions in table 1 have been tested on a sample of 10 people, and how easy the question is to answer and how easily understandable the question itself is have been contrasted.

The final result of the assessment is obtained by adding the scores for each set of criteria together to get a total score for each category, and then adding the scores for each category together to find out the level for each impact. The higher the final score, the better the energy performance of the building. Table 4 shows the different levels based on the four categories of SPE and this is compared to the other assessment methods, LEED and BREEAM.

Table 4. Rating levels for the different methods

CLASSIFICATION	LEED	BREEAM ES	SPE SUS	SPE ECO	SPE EN	SPE SO
Level 1		≥30	≤75	≤25	≤25	≤25
Level 2	40-49	≥45	76-120	26-40	26-40	26-40
Level 3	50-59	≥55	121-180	41-60	41-60	41-60
Level 4	60-79	≥70	181-240	61-80	61-80	61-80
Level 5	80-110	≥85	241-300	81-100	81-100	81-100

In summary, version 1.0 of SPE is structured on some questions for each criteria and a score is given depending on the user's answers. A score for each category is given at the end of the process and the sum of these scores gives us the final result for the four impact types: economic, social, environmental and sustainability. This last impact type is calculated by adding together the other three scores the weights of which in relation to the final sustainability score are 33.5% each.

The methodological strategy for the creation of SPE is that the target users are potential home-buyers or tenants and that the tool should encourage reflection on the part of the user as well as an assessment of sustainability criteria to help foment demand for sustainable homes.

3.2.- Case study of a residential building

This section introduces a real case rated in the design phase by BREEAM as level 2 (table 4), and also rated by SPE. To ensure a thorough analysis and to be able to compare results LEED has also been taken into account.

The residential property subject of this study is flat number three on the first floor of block C, which forms part of the C-D building phase. It is a newly-built, multi-family residential property built in the form of a V (fig.3). It consists of a lower ground floor, a ground floor and seven stories and it is divided into blocks. It is located in the city centre in Avinguda Vidal i Barraquer in Tarragona, Spain, and it is built on a former industrial site.

Fig.3 New building

The total area of phase C-D is 1,6668.39 m2, 1,016.48 m2 of which is occupied by the building. The remaining 651.91 m2 is a patio garden with native Mediterranean flora that needs little water. In phase C-D there are 52 two, three and four-bedroom homes (fig.4, fig.5, fig.6).

The building in which the case study property is located (fig.3) features various passive measures, such as 6-8cm thick extruded polystyrene insulation, exterior walls that are suitably ventilated for a Mediterranean climate and thermally insulated windows, all of which help to limit non-renewable primary energy consumption to 45Kwh/m2 per year and to limit energy demand for heating and cooling to 15Kwh/m2 per year. The building features such active measures as aerothermal equipment for air-conditioning and sanitary hot water, which ensures a high level of energy efficiency and comfort as well as the application of renewable energy. There are also different water-saving measures and a system for re-using rainwater for the patio garden area. The building is in the centre of Tarragona, thus it is easily accessed by public transport and it is conveniently located for all services.

Fig. 4 Floor layout

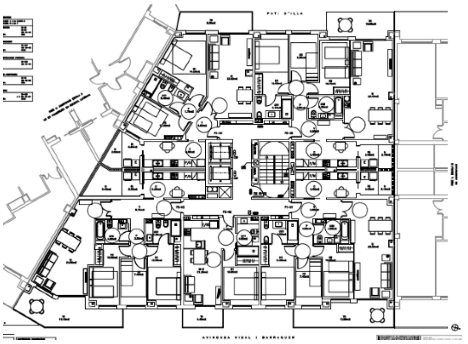


Fig.5 Exterior walls

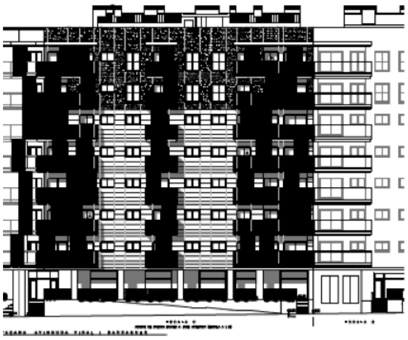


Fig.6 Building section

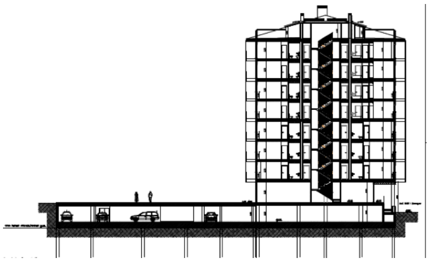
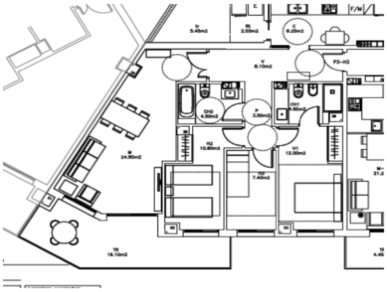


Fig.7 Layout of flat 1-3ª



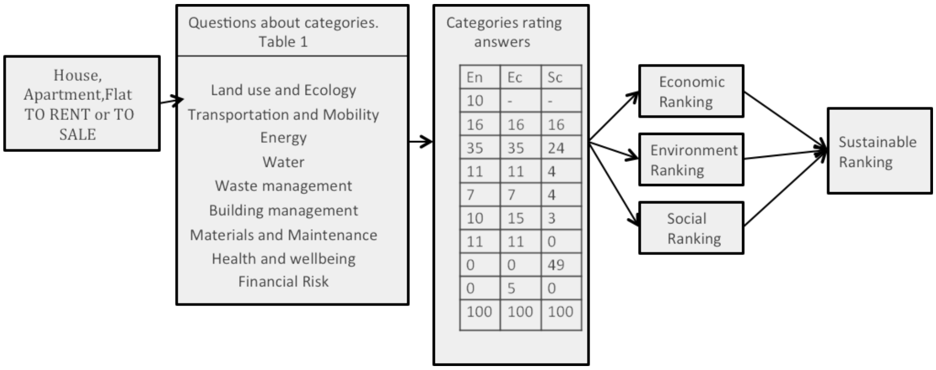
Flat 1-3ª is 84.8 m2 with a 21.55 m2 terrace and a 2.55 m2 utility area: a total of 108 m2. It has three bedrooms and two bathrooms. All of the appliances in the kitchen are A+++-rated, the lifts are highly energy-efficient and the lighting both in the flat and in the communal areas is LED. All of the rooms in the flat except the kitchen have natural light. There are no access problems either inside the property or to and from the building itself. The kitchen features a space for separating household waste – glass, cartons, plastic and organic waste - for recycling (Fig.8)(Fig.9).

In terms of energy performance the Spain Energy Performance of Building Directive (EPBD) rates the property as B. The flooring is parquet, the toilets have a dual flush and the taps have aerators to save energy. There is a shower in one of the bathrooms and a bath in the other, which saves water and is also important from the perspective of health and well-being.

Fig.8 Bathroom and bedroom

Fig.9 Kitchen

Fig.10. SPE evaluation process



En	Ec	Sc
10	-	-
16	16	16
35	35	24
11	11	4
7	7	4
10	15	3
11	11	0
0	0	49
0	5	0
100	100	100

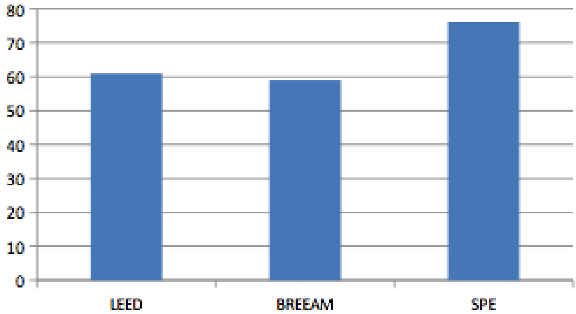
Table 5. Results for the different rating systems

CATEGORIES	CERT. BREEAM ES	%WEIGHT BREEAM	CERT SPE SOST	%WEIGHT SPE	CERT.LEED	%WEIGHT LEED
LAND USE AND ECOLOGY	4	7%	22	10%	6	10%
TRANSPORT AND MOBILITY	5	8%	18	8%	9	15%
ENERGY	19	32%	82	36%	22	36%
WATER	4	7%	25,5	11%	7	11%
WASTE MANAGEMENT	6	10%	24	11%		
BUILDING MANAGEMENT			7	3%		
MATERIALS AND MAINTENANCE	6	10%	12	5%	7	11%
HEALTH AND WELL-BEING	5	8%	33	14%		
FINANCIAL RISK			5	2%		
SITE MANAGEMENT	5	8%				
POLLUTION	5	8%				
INDOOR ENVIRONMENTAL QUALITY					10	16%
TOTAL	59	100%	228,5	100%	61	100%

4.- Results and discussion

Once the data collected (table 5) have been analysed and the BREEAM, LEED and SPE rating processes finalised (fig.10), it can be concluded that BREEAM rates the building as level 2, while LEED and SPE rate it as level 4 (fig.11). It is important to remember, however, that BREEAM and LEED assess the building as a whole, while SPE rates the individual property. With SPE each property within a building can be rated independently of the rest of the building.

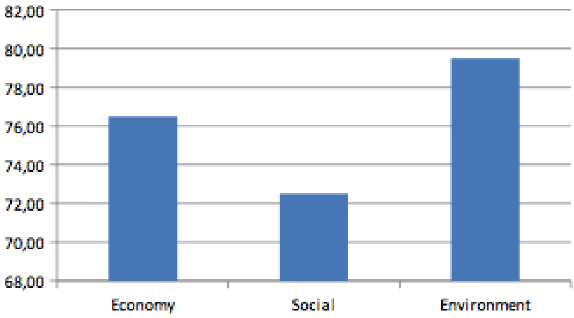
Fig.11 Results



This study has shown that all building sustainability assessment methods, and specifically those analysed in this study, have the same objective: to foment sustainable building. The first point to make is that most existing assessment methods are aimed at developers, investors, builders, designers and building technicians: in other words at the product manufacturing process. SPE, on the other hand, is designed specifically for the users of buildings, and is therefore aimed at product demand. The second point to make is that regarding sustainability or, more specifically, the three pillars of sustainability - economic, environmental and social – LEED and BREEAM place more importance on environmental factors as opposed to economic or social, whereas in SBTool and SPE the three pillars are given equal importance (table 2).

Fig.12 shows the results for the different impacts and the level they are rated at in the case study.

Fig.12 SPE impacts: Economic, Social, Environmental for case study property



If we make a quantitative comparison and we examine the weights of the different categories, both similarities and differences can be observed (table 6).

Table 6. Category weights

CATEGORIES	%WEIGHT BREEAM	%WEIGHT SPE	%WEIGHT LEED
LAND USE AND ECOLOGY	7%	10%	10%
TRANSPORT AND MOBILITY	8%	8%	15%
ENERGY	32%	36%	36%
WATER	7%	11%	11%
WASTE MANAGEMENT	10%	11%	
BUILDING MANAGEMENT		3%	
MATERIALS AND MAINTENANCE	10%	5%	11%
HEALTH AND WELL-BEING	8%	14%	
FINANCIAL RISK		2%	
SITE MANAGEMENT	8%		
POLLUTION	8%		
INDOOR ENVIRONMENTAL QUALITY			16%
TOTAL	100%	100%	100%

How the LEED and BREEAM rating processes are carried out must be mentioned. To obtain a final score, each category must be assigned some credits or requirements (each rating system uses its own nomenclature) which have a point rating. Proof of compliance or some calculations must be provided in order to gain these points. This process, therefore, generates costs that make the rating system expensive, which is why many investors use the strategy of placing the building at a certain level in order to avoid having to gain certain points, not because the building does not comply but so as not to have to demonstrate these features and thereby increase costs. A clear example is the acoustic credit: to prove that the building complies with established levels to gain these points acoustic tests must be carried about by a qualified technician and a report provided.

This is the case with the study property in Tarragona. With BREEAM there is also the added complication that the assessor carrying out the rating process cannot provide proof of certain features too; a third party must carry out tests and provide reports which the assessor then validates. This is partly the reason why LEED and SPE rate the flat at level 4 and BREEAM rates it at level 2.

As can be seen in table 6, the weights and scores obtained for the different categories are generally similar for the three rating systems in question. This helps to validate SPE. However, the peculiarities of each method must be taken into consideration.
The analysis shows that the weights of the categories ‘Land Use and Ecology’ and ‘Energy’ and ‘Water’ are comparable in the three rating systems: BREEAM is the only method that is slightly different at between 2-4% for reasons previously mentioned.

Regarding the ‘Transport and Mobility’ category, the results of the analysis in table 6, which shows the weight of each category for the different methods, demonstrate that the result for LEED is double that of BREEAM, and the difference is also exactly double in the final result.

‘Waste Management’ is a specific case which depends on the rating system type. As LEED BD+C V4 is a method for newly-constructed buildings and large buildings with four or more floors that have undergone major reforms, it does not include a ‘Waste Management’ category for residential buildings, whereas BREEAM and SPE do. If we compare the results of BREEAM and SPE we can see that the weight for both is 8%.

The difference between the basic idea of SPE and that of LEED and BREEAM is clearly illustrated in the ‘Materials’ category. This category has a weight of 11% in LEED and 10% in BREEAM as they take into account environmental aspects of materials such as life cycle analysis and the percentage of recycled materials, among others. The fact that SPE is aimed at users of residential buildings – home buyers or tenants who are not specialist materials technicians - means that the SPE rating process is carried out once the building phase is finished and not at the beginning of the project, as is the case with LEED and BREEAM.

Other categories, such as ‘Site Management’ and ‘Pollution’ are peculiar to BREEAM because they are aspects that affect the building process, the phase that SPE is not concerned with. In LEED ‘Site Management’ is included in the ‘Sustainable Sites’ category.

Table 6 also shows that LEED has no ‘Health and Well-being’ category because the criteria included in this category are incorporated into ‘Indoor Environmental Quality’. This category carries a weight of 16 % in LEED, 14% in SPE and 8% in BREEAM.

In these rating systems it must be remembered that many of the environmental impacts are caused by air-conditioning systems (HVAC) and sanitary hot water systems. Therefore, these impacts directly affect economic aspects even though this is not stated explicitly.

‘Building Management’ and ‘Financial Risk’ are two new concepts which are very important in SPE as they are linked to the idea that sustainable buildings should be valued more highly economically. This weight in relation to the final price of the building can be as much as 5%. Both studies and experience have proven that having a maintenance programme makes a building more valuable and lengthens its useful lifespan.

The SPE rating system is especially relevant when buying or renting a property that is 10 or more years old as the fact that the building systems and installations are obsolete in these buildings is more evident and this is reflected in the final rating.

5.-Conclusion

This study analyses the creation of a new building environmental assessment method called SPE, which is aimed at home buyers and tenants. It is quantitatively compared with two existing building environmental assessment systems, LEED and BREEAM, and is based on a real case study.

The innovative contribution of this study is the development of a tool which assesses the sustainability of residential buildings and is aimed at potential users of these properties, or in other words, at product demand. Existing certificates assess buildings and are aimed at investors, designers, and constructors, or in other words, at product supply. This change in perspective is important as the fact that SPE is aimed at product demand means that it will help to foment sustainable building construction.

The case study has demonstrated the similarity between the weights of the categories in the assessment methods analysed, which means that SPE can be authorised, although certain factors must be taken into consideration. Due to the elevated cost of providing proof of compliance with certain features, which is required in LEED and BREEAM, some aspects, such as building acoustics, are sometimes left aside, which goes against good practice.

SPE is aimed at residential properties and the final scores obtained can vary according to the characteristics of each individual property within a building. This is not possible with international assessment systems.

Another factor to take into consideration is the weight of the different impacts. In SPE the three impacts – economic, environmental and social – carry the same weight and thus the results reflect the magnitude of each impact; they can show, for example, that a building performs better environmentally than economically or socially. With residential buildings studied using LEED BD+C v4 and BREEAM ES, on the other hand, the weight of environmental impacts are between 80-85%, social impacts between 15-20% and economic impacts between 0%-5%.

Another important aspect of these assessment systems is the mobility criteria. In small villages where there is no public transport and little work and where inhabitants must commute these criteria have significant impacts. This aspect, therefore, directly influences territorial development policies in countries and how this needs to be dealt with if rural depopulation and massive population growth in cities is to be avoided.

The aim in developing this rating system is to make users of residential buildings more aware of building sustainability criteria and their potential economic, environmental and social implications.

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6. CONCLUSIONES Y DESARROLLOS FUTUROS

En los artículos presentados en los capítulos anteriores se recogen las distintas conclusiones de las diferentes fases de investigación. Se ha considerado pertinente recoger y recopilar, en este capítulo, dichas conclusiones de forma conjunta para ofrecer una visión global de los resultados obtenidos.

6.1 Conclusiones

La Tesis se ha focalizado en el desarrollo de metodologías y herramientas para facilitar la aplicación de criterios de eficiencia energética y de sostenibilidad para los técnicos y la sociedad en general, con el objetivo de aportar más conocimiento sobre el desarrollo sostenible.

Por esta razón esta tesis se ha desarrollado desde una visión concreta como la creación de una metodología de eficiencia energética de los sistemas constructivos hasta llegar a una visión general como el desarrollo de una herramienta para la evaluación de la sostenibilidad, teniendo siempre en cuenta la perspectiva del ACV y los impactos económicos, ambientales y sociales.

El trabajo desarrollado en el capítulo 3 nos ofrece las siguientes conclusiones:

- Confirmar que el certificado de eficiencia energética y las medidas de eficiencia energética que se empezaron a aplicar en la UE en aplicación de la Directiva 2002/91/EC y posteriormente por la Directiva 2010/31/EC, no tienen en cuenta el análisis del Ciclo de Vida en el momento de determinar la etiqueta energética.

- Verificar que no es directamente proporcional el consumo energético con la producción de CO2 ya que hay sistemas de producción de energía que emiten más CO2 que otros y no por ésto el edificio deja de consumir menos energía. Por lo tanto es importante que los países mejoren el mix energético aumentando la producción de energía eléctrica con renovables.

- Recomendar que para intervenir sobre el consumo energético en la etapa de uso es imprescindible intervenir en la fase de diseño del edificio, donde los sistemas constructivos son definidos y donde se ha demostrado que mediante la limitación de la demanda se puede actuar para cambiar las emisiones de CO2 generadas por el consumo energético.

De acuerdo con el trabajo desarrollado en el capítulo 4 las principales conclusiones son:

- Confirmar que aunque las bases de cálculo de las emisiones y de la eficiencia energética son las mismas en toda Europa, las diferentes metodologías aplicadas en cada país dan resultados diferentes y como consecuencia de ello es de gran dificultad entablar una comparación.

- Verificar que la aplicación de la Directiva sobre EPBD en España y los primeros resultados podemos comprobar que el proceso de mejora aun es muy alto.

- Dejar constancia que la Directiva sobre EPBD no tiene en consideración la energía embebida de los materiales.

- Confirmar que la metodología utilizada para el cálculo y elaboración de los informes EPD estan influenciados por los criterios de los técnicos que los realizan.

- Comentar que dentro de una misma herramienta de simulación se ha detectado diferencias entre los valores absolutos y de porcentaje.

De acuerdo con el trabajo desarrollado en el capítulo 5 las principales conclusiones son:

- Aportar una metodología sencilla que permite calcular el nivel de sostenibilidad de cualquier tipología de edificio de viviendas y unidades de viviendas.

- Proponer un sistema que equilibra el peso de los distintos impactos (económico, social, medioambiental) en contraposición a otras metodologías o sistemas que distribuyen estos impactos de distinta forma.

- Poner en consideración el sistema de puntuación utilizado por las grandes certificaciones de edificios para evaluar el transporte público dentro del apartado de movilidad, ya que penaliza en demasía aquellos nucleos de población que por su tamaño hacen inviable disponer de servicios de transporte público. Este aspecto influye directamente sobre la tipología de desarrollo territorial de los estados y como se trata esta problemática para que no se produzca la desertización de pequeñas poblaciones y el crecimiento masivo de las grandes ciudades.

6.2 Resultados de la Tesis y aplicabilidad

La siguiente lista contiene las publicaciones presentadas como capítulos de esta Tesis y resultado del misma.

Castellano J., Castellano D., Ribera A., Ciurana J. (2014). Development of a scale of building construction systems according to CO2 emissions in the use stage of their life cycle. Building and Environment 82 (2014), 618-627.

Castellano J., Castellano D., Ribera A., Ciurana J. (2015). Developing a simplified methodology to calculate CO2/m2 emissions per year in the use phase of newly-built, single-family houses. Energy and Buildings (2015).

Castellano J., Ribera A., Ciurana J. (2015). Sustainable property expert (SPE), a methodology and tool for a sustainable housing assessment. Journal of Cleaner Production.

La aplicabilidad de las investigaciones realizadas en esta Tesis es uno de los objetivos primordiales, ya que en el desarrollo de metodologías y herramientas se ha pretendido que fueran útiles para técnicos y sociedad en general, esto sin menospreciar la rigurosidad en el desarrollo de las mismas.

El primer y segundo artículo han tenido como objetivo la divulgación de las emisiones de CO2 de una forma fácil y que su aplicación en proyectos de Arquitectura e Ingeniería no resultara de ninguna dificultad. Al mismo tiempo convirtiendo, aportando el artículo del capítulo 3 en un novedoso sistema de clasificación que podría aparecer en todos libros de precios como un nuevo factor de decisión para la elección del sistema constructivo.

En el artículo desarrollado en el capítulo 5 se ha pretendido desarrollar una nueva metodología que valorara los impactos de la sostenibilidad al alcance del público en general con la finalidad de toma de conciencia sobre todos los aspectos de la sostenibilidad.

6.3 Contribuciones de la Tesis

Las principales contribuciones del trabajo realizado presentado en esta Tesis se resumen a continuación:

- El desarrollo de este trabajo ha creado un sistema que permite clasificar diferentes opciones de soluciones constructivas para facilitar y mejorar la elección del sistema constructivo y no tener que realizar la simulación al final del proceso constructivo.

- La metodología desarrollada en la escala de clasificación de emisiones para sistemas constructivos y validada en el caso de estudio es extrapolable a otros sistemas constructivos como pueden ser fachadas, ventanas, instalaciones, etc.

- La metodología desarrollada mediante una fórmula aritmética fácil de aplicar servirá para que los diseñadores de edificios tengan en cuenta las emisiones de CO2 como un parámetro clave en el diseño, que les permitirá estudiar cuales son las posibilidades o factores de mejora y así permitir la corrección del diseño realizado, afectando a los costes, materiales, instalaciones, etc.

- La aportación innovadora que se realiza en este trabajo es el desarrollo de una herramienta que evalúa la sostenibilidad de una vivienda y actúa sobre el futuro usuario o sea sobre la demanda. Las otras certificaciones existentes evalúan la sostenibilidad del edificio actuando sobre los inversores, diseñadores, constructores o sea sobre la producción.
Este cambio de perspectiva es importante ya que actúa sobre la demanda, ayudando a acelerar la construcción de edificios sostenibles.

- El desarrollo de esta herramienta cumple con el objetivo más importante que es concienciar los usuarios de viviendas sobre los criterios de sostenibilidad en la edificación y como estas pueden afectar económicamente, socialmente (salud y bienestar) como ambientalmente.

6.4 Trabajos futuros

En este punto queremos mostrar la previsión de futuros estudios a desarrollar para continuar la investigación sobre los diferentes aspectos de la sostenibilidad.

- Comprobar cómo se modifican las emisiones de CO2 de un edificio en función en función de la altura y su orientación en diferentes programas de simulación.

- Mejorar de la fórmula aritmética para el cálculo de emisiones de CO2 desarrollada para edificios de nueva construcción para su utilización en edificios existentes.

- Desarrollar de una herramienta para la elección de oficinas con criterios de sostenibilidad.

- Incorporar la energía embebida de los materiales en los diferentes procesos de cálculos de emisiones de CO2.

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