Determining the material intensities of buildings selected by random sampling: the case study of Vienna

Jakob Lederer[a,b,+], Johann Fellner[a], Andreas Gassner[a], Karin Gruhler[c], Georg Schiller[c]

Supporting Document v5, 22.10.2020

a) Christian Doppler Laboratory for Anthropogenic Resources, Institute for Water Quality and Resource Management, TU Wien, Karlsplatz 13/226, 1040 Vienna, Austria

b) Institute of Chemical, Environmental and Bioscience Engineering, TU Wien, Getreidemarkt 9/166, 1060 Vienna, Austria

c) Leibniz Institute of Ecological Urban and Regional Development (IOER), Weberplatz 1, 01217 Dresden, Germany

+) corresponding author

Table of content

List of tables

List of figures

Description of Supporting Information

The supporting information consists of this "supporting document", and three "supporting data" files.

Supporting document

The present supporting document, which can be downloaded from the Journal's article webpage, contains information relevant for a better understanding of the associated article. Thus, the article provides a detailed reference to this supporting document and each section. The numbering of the sections and subsections in this supporting document mirrors the numbering in the article. Furthermore, the supporting document provides reference to the supporting data files.

Supporting data

The other supporting information are three "supporting data" files in excel that can be downloaded from GitHub. These files are sub-sequentially described:

Supporting_data_1 contains the extended digital building model (DBM).

Supporting_data_2 contains different sheets with information on:

- Object (or building) categories distinguished (sheet *2-1_Categories*)
- Material bulk densities as built-in (sheet *2-2_Densities*) to convert between volumes and mass
- The 256 samples randomly selected (sheet *2-3_Samples*)
- General results of the calculations as presented in the article ((sheet *3-1_Results-general-paper*)
- Material intensities MI in ton per m³ GV_{eaves}, using the object (buildings) classification according to the information from the digital building model (sheet *3-2_MI-GVeaves-DBM-paper*)
- Material intensities MI in ton per m³ $GV_{building}$, using the object (buildings) classification according to the information from the plan analysis, after re-classification of buildings with no information or other buildings (sheet *3-3_MI-GVbuilding-plan-paper*)
- Material intensities MI in ton per m³ GV_{agl}, using the object (buildings) classification according to the information from the plan analysis, after re-classification of buildings with no information or other buildings (sheet *3-4_MI-GVAGL-plan-paper*)

Supporting_data_3 contains a re-estimation of the material stock in buildings in Vienna

1 Introduction

No supporting information.

2 Methods and materials

2.1 Sampling procedure

2.1.1 The original population

The original population for selecting the samples are all objects that are classified as buildings or part of buildings in the extended Digital Building Model (DBM) of Vienna as of the year 2013. This extended DBM model contained 599,962 objects. All objects in the extended DBM are listed in the supporting information, i.e. the supporing_data_1. It is an Excel Binary file whose first lines are shown in Table S1:

Table S1 The first lines (including header) of the extended DBM as presented in supporting_data_1

Object-ID	h_{eaves}	GFA_p	GV_{eaves}	Use-Category	Age-category	Size-category
1	1	13	13	2	3	0
2	15	555	8485	0	0	3

Subsequently, each column header of the table in supporting_data_1, shown in Table S1, is briefly described:

Object-ID — This is the unique identification of each object in the original DBM in Vienna. The Object-IDs are numbered from 1 to 599,962. These Object-IDs come from the original DBM that can be downloaded from Vienna's open government portal.

h_{eaves} — This is the height of each object, measured from the surface up to the eaves. This value is calculated in the original DBM. Therein, it is generated by combining the digital land model (DLM), which gives information on the height of the surface above sea level, with the DBM, which gives information on the height of the eaves of an object above sea level. The calculated difference between this height in one point in the DBM and the DLM gives the h_{eaves}.

GFA_p — This is the gross floor area per floor p, assuming that each floor occupies more or less the same area. Thus, the GFA_p equals the ground area GA. It is included in the data of the original DBM and therein, it is simply measured.

GV_{eaves} — This is the gross volume of the object above ground level, from the surface up to the eaves. It is calculated based on the original DBM by multiplying the GFA_p by the h_{eaves}.

Use-category — The use-category is not part of the original DBM, but a unique feature in the extended DBM as created by Kleemann et al. (2017). In general, four use categories are distinguished in the extended DBM, namely residential, service, industrial, and other buildings. The latter includes also objects with initially no information on their use in the extended DBM. The codes for the use-categories are shown in Table S2.

Table S2 Use-categories distinguished in the extended DBM

Use	Abbreviation	Number
Residential	R	1
Service	S	2
Industrie	I	3
unknown / other	O	0

Age-category Like with the use-category, the age-category is not part of the original DBM, but a result from Kleemann et al. (2017) and thus also unique to the extended DBM. The age-category gives information on the age period in which an object was constructed. The age-categories distinguished refer to buildings built before 1919 (<1919), between 1919 and 1945 (1919-1945), between 1946 and 1976 (1946-1976), between 1977 and 1996 (1977-1996), and after 1996 (>1996). In addition, there are object for which the age-category is not known. These objects are classified as "no-information" with respect to their age category. See Table S3 for the age-categories distinguished.

Table S3 Age-categories distinguished in the extended DBM

Age	Number
<1919	1
1919 - 1945	2
1946 - 1976	3
1977 - 1996	4
>1996	5
unknown	0

Size-category The size-category categorizes objects according to their GV_{eaves}. The information on the GV_{eaves} come from the original DBM. The classification of object into size-categories was made based on the following considerations: Objects smaller than 250 m³ GV_{eaves} make a large portion of the DBM, but contribute little to the total GV_{eaves} of all objects. Thus, these were categorized as 0. Objects between 250 and 1,000 m³ GV_{eaves} are of a size typical for single family or two apartment houses. Objects between 1,000 and 5,000 m³ GV_{eaves} are of a size typical for multi apartment buildings containing between three and ten apartments. Objects larger than 5,000 m³ GV_{eaves} are of a size typical for multi apartment buildings containing more than ten apartments. The main reason for using these size-classes that link the size of a residential building to the number of apartments within the building is to create a link to national statistical data, as Statistics Austria, the statistical department of the country, uses the same classification. This makes it easier in case that the data should later be used in combination with national statistics data, for instance to calculated total material stocks. Table S4 shows the size-categories thus distinguished.

Table S4 Age-categories distinguished in the extended DBM

Gross volume GV_{eaves} in m³	Number
<250	0
250-1000	1
1000-5000	2
>5000	3

The object categories distinguished are also shown in the supporting_data_2, sheet 2_1.

2.1.2 Selection of samples

The extended DBM model as described above contained 599,962 objects. These objects correspond to about 200,000 buildings as in some cases, one building consists of two or more objects. Figure S1 shows an example where the object corresponds to a full building (left), and an example where an object

corresponds to a part of a building (right). In the case of the latter, the building consists of several objects.

Figure S1 An example for an object which is a full building on the left (Object Number 100345, Adress No. 44), and an object which is only part of a building on the right (Object Number 82770, Adress No. 156). Images from the DBM and the City Map of Vienna (Kleemann et al. 2017; MA41 2020a, 2020b).

2.2 The analysis of samples

2.2.1 Analysis of building documents

The analysis of plan documents was the most important part of this study. Figure S2 and Figure S3 show two examples of plans as found in the documents for residential buildings of different age.

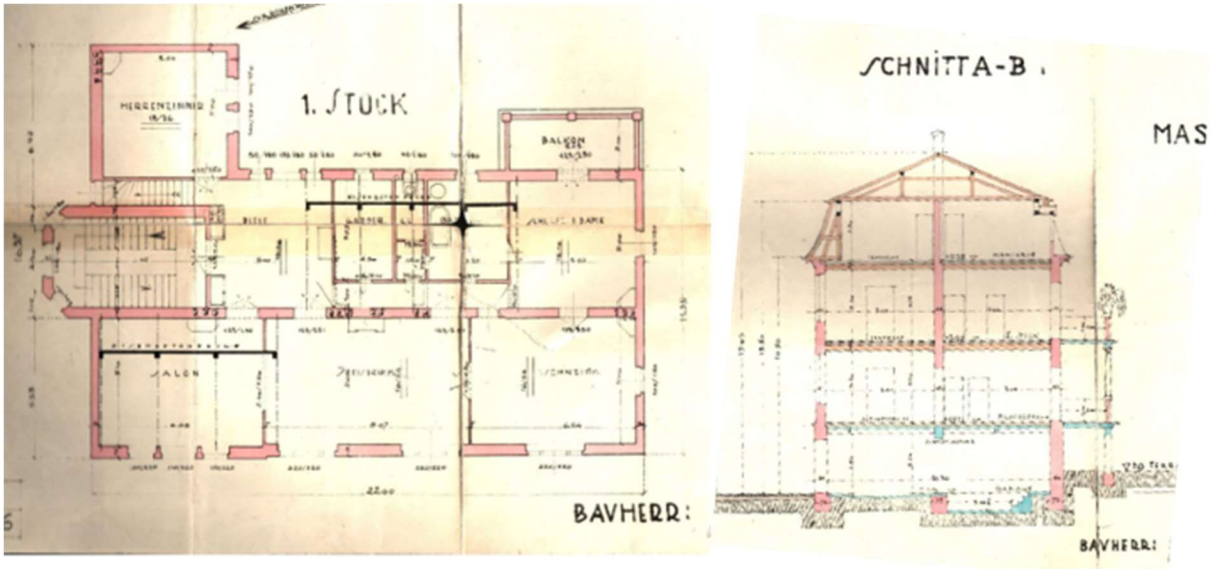


Figure S2 Plan document from a residential building constructed in the year 1924 (Object Number 49727, Address No. 55)

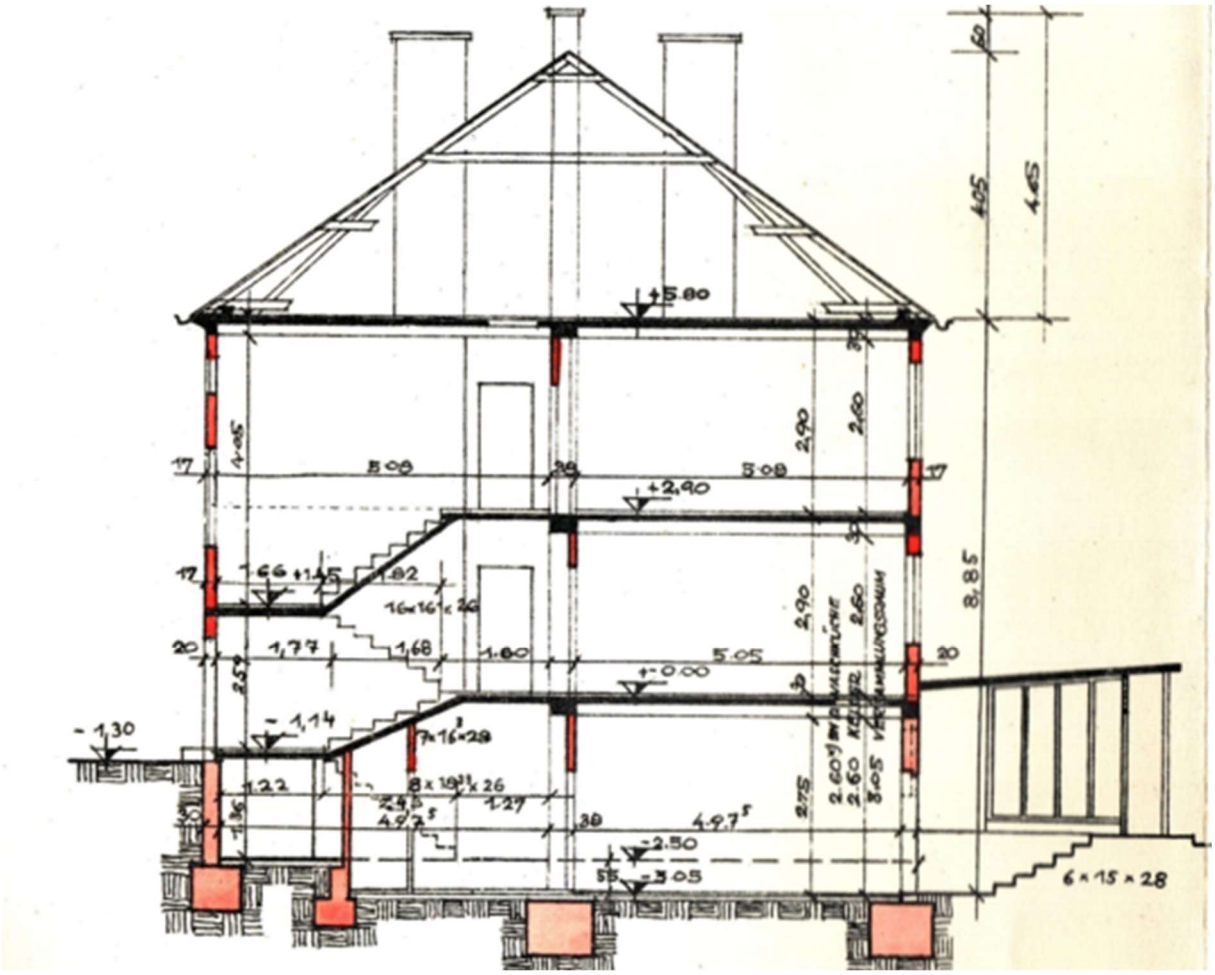


Figure S3 Cross section from a residential building constructed in the year 1956 (Object Number 16932, Adress No. 22)

2.2.2 Analysis of aerial images to validate attic extensions and street view to validate the renovation status of windows in older buildings

Aerial images were used to validate whether buildings constructed before 1946 had an attic extension or not, as in these the attic was initially not used for living, service, or industry. For buildings after 1945, it was assumed that the attic was already initially used for the designated purpose of the building (Gruber et al. 2018). Figure S4 shows an aerial images from the Vienna City Map (MA41 2020b). From these images, it is possible to control whether a building contains an attic extension or not.

Figure S4 Aerial image highlighting two buildings of the same age and use category (<1919, residential) by a white dotted line. The building on the left image (Object ID 5663, Adress No. 6) contains an attic extension, which is visible by the terraces and roof windows. The building on the right image (Object ID 61425, Adress No. 2) does not have the same elements indicating an attic extension. Aerial images taken from Vienna's city map (MA41 2020b)

The renovation of windows (i.e. exchange) is an important measure in Vienna to reduce the heating energy demand of older buildings. Unfortunately, a lot of these renovations are not recorded in plan documents, as they are sometimes carried out by tenants without contacting the land lord or building authorities. As old windows are very different than new ones, it is possible to validate the renovation status of the windows of older buildings from images as produced and shown by Google Street View. Figure S5 shows an example where both, old and new windows in buildings constructed before the year 1919 in Vienna are contained, clearly showing the differences between both.

Figure S5 Google street view image of a building constructed before the year 1919 image (Object ID 61425, Adress No. 2). The old wood-framed box-type windows are still visible in the first floor, while in the ground floor and the mezzanine, these windows were already replaced by new PVC-framed windows.

2.2.3 Material considered and their bulk densities

The materials considered were these were it was possible to determine their quantities, based on plan documents. Obviously, these are also these of higher quantitative relevance (Kleemann et al. 2017). In any case, the bulk density of the material is required in order convert from plan-measured dimensions (volumes, areas) to material quantities. Table S5 shows the materials and their densities.

Table S5 Materials considered and their bulk volume or area densities

Material code and group, age category, renovation works	**Unit determined by plan analysis**	**Density and material content per unit**	**Literature sources to determine the density and material content**	**Applies to value**	**Refers to equation in the manuscript**
Concrete	$m^3_{concrete}$	2.40 t/m³	ASI (2011)	$\rho_{V,m}$	6
Full brickwork	$m^3_{brickwork}$	1.60 t/m³		$\rho_{V,m}$	6
Hollow brickwork	$m^3_{brickwork}$	1.00 t/m³		$\rho_{V,m}$	6
Gravel and sand	$m^3_{gravel\ and\ sand}$	2.00 t/m³		$\rho_{V,m}$	6
Construction steel	$m^3_{construct\ steel}$	7.80 t/m³		$\rho_{V,m}$	6
Rebar, 1919-1976	m^3_{RC}	0.08 t/m^3_{RC}	Baumeister (1955)	c_{rebar}	8
Rebar, >1976	m^3_{RC}	0.15 t/m^3_{RC}		c_{rebar}	8

Rebar, <1946, rooftop-extension	m^3_{RC}	0.15 t/m^3_{RC}	Hoffmann & Krause (2011)	c_{rebar}	8
Wood	m^3_{wood}	0.60 t/m^3	ASI (2011)	$\rho_{V,m}$	6
Mineral wool	$m^3_{mineral\ wool}$	0.04 t/m^3		$\rho_{V,m}$	6
Polystyrene	$m^3_{polystyrene}$	0.03 t/m^3		$\rho_{V,m}$	6
Glass, <1977	m^2_{glass}	0.01 t/m^2	Meyer-Bohe (2008)	$\rho_{A,m}$	7
Glass, 1977-1996	m^2_{glass}	0.02 t/m^2		$\rho_{A,m}$	7
Glass, >1996	m^2_{glass}	0.03 t/m^2		$\rho_{A,m}$	7
Glass, <1977, new windows	m^2_{glass}	0.03 t/m^2		$\rho_{A,m}$	7
Gypsum	m^3_{gypsum}	1.00 t/m^3	ASI (2011)	$\rho_{V,m}$	6

2.2.4 Dimensions and material intensities of the sampled objects

Supporting_data_2, sheet 2-3, shows the values for each sample determined based on plan documents, aerial images and google street view. Table S6 shows the first three rows in this table in sheet 2-3, including a description of each paratmeter. Note that here in the supporting_document, rows and columns are inverted.

Table S6 First three rows of the data table from supporting_data_2, sheet 2-3. Rows are shown here as columns.

No.	Parameter	Symbol	Unit	Description
1	Object-ID DBM	Number		Object-ID of selected objects, taken from the original DBM
2	Circumstance		m	Taken from the original DBM
3	Adress (number)	Number		Taken from the extended DBM
4	Eaves height	h_{eaves}	m	Taken from the original DBM
5	Building ground area DBM	GA	m^2	Taken from the original DBM
6	Gross volume eaves DBM	GV_{eaves}	m^3	Calculated based on the original DBM
7	Use-category DBM	Use_{DBM}		Use-category according to the extended DBM
8	Age-category DBM	Age_{DBM}		Age-category according to the extended DBM
9	Size-category (volume) DBM	$Size_{DBM}$		Size-category according to the extended DBM
10	Date collection plan documents	Date		Date when the plan document was collected from the authorities
11	Full or part of a building plan	full/part		Distinction whether the object is full building, or part of a building, according to the plan documents
12	Attic-extension plan	yes=1 no=0		Existing attic-extension in buildings constructed before 1946, based on plan documents and aerial image
13	Parking in basement plan	yes=1 no=0		Existing parking garage in the basement, based on plan documents
14	Thermal insulation walls plan	yes=1 no=0		Thermal insulation of walls in buildings constructed before 1981, based on plan documents
15	Thermal insulation roof plan	yes=1 no=0		Thermal insulation of roofs in buildings constructed before 1981, based on plan documents
16	New windows plan	yes=1 no=0		New windows in buildings constructed before 1981, based on plan documents and google street view
17	Thermal renovation plan	yes=1 no=0		Complete thermal insulation of buildings constructed before 1981, based on plan documents
18	Use-category plan	Use_{plan}		Use-category according to the plan (updated)
19	Age-category plan	Age_{plan}		Age-category according to the plan (updated)
20	Age-category windows plan	$Age\text{-}windows_{plan,streetview}$		Age-category of only windows according to the plan (updated)
21	Height basement plan	h_{base}	m	Height of the basement according to the plan
22	Height eaves plan	h_{eaves}	m	Height of the eaves according to the plan
23	Height roof ridge plan	h_{ridge}	m	Height of the ridge according to the plan
24	Height above-ground level plan	$h_{agl} = h_{eaves}+h_{ridge}$	m	Height of the above-ground level part according to the plan
25	Height total plan	$h_{buiding} = h_{eaves}+h_{ridge}+h_{base}$	m	Height of the total building according to the plan
26	Height basement floor -3	h-3	m	Height of the 3rd floor in the basement according to the plan
27	Height basement floor -2	h-2	m	Height of the 2nd floor in the basement according to the plan
28	Height basement floor -1	h-1	m	Height of the 1st floor in the basement basement according to the plan
29	Height floor 0	h0	m	Height of the ground floor according to the plan
30	Height floor (incl. attic if used) 1	h1	m	Height of the 1st floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
31	Height floor (incl. attic if used) 2	h2	m	Height of the 2nd floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
32	Height floor (incl. attic if used) 3	h3	m	Height of the 3rd floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
33	Height floor (incl. attic if used) 4	h4	m	Height of the 4th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
34	Height floor (incl. attic if used) 5	h5	m	Height of the 5th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
35	Height floor (incl. attic if used) 6	h6	m	Height of the 6th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
36	Height floor (incl. attic if used) 7	h7	m	Height of the 7th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
37	Height floor (incl. attic if used) 8	h8	m	Height of the 8th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
38	Height floor (incl. attic if used) 9			Height of the 9th floor according to the plan – if this floor is in the attic, then only considered when used (for living, etc.)
39	Height floor total AGL plan			Height of all floors above ground level
40	Gross building ground area plan	GA_{plan}	m^2	

No.	Parameter	Symbol	Unit	Description
41	Number of floors total (incl. basement, unused attic)	NF	No.	Total number of floors
42	Gross building floor area total	GFA_{total}	m²	Total gross floor area
43	Useable floor area conditioned	$UFA_{conditioned}$	m²	Useable floor area of conditioned parts of the building
44	Useable floor area un-conditioned	$UFA_{unconditioned}$	m²	Useable floor area of unconditioned parts of the building (e.g. attics used solely for storage, but not heated)
45	Useable floor area total	UFA_{total}	m²	Useable floor area total (conditioned + unconditioned)
46	Share UFA_{total} / GFA			Share total UFA to total GVA
47	Gross volume basement plan	$GV_{basement}$	m³	Gross volume of the basement of the building, according to the plan documents
48	Gross volume eaves plan	GV_{eaves}	m³	Gross volume of the building above ground level, but only up to the eaves, according to the plan documents
49	Gross volume roof plan	GV_{roof}	m³	Gross volume of the ridge roof of the building, according to the plan documents
50	Gross volume above-ground level plan	$GV_{agl} = h_{agl}*GA$	m³	Gross volume of the building above ground level, but up to the ridge (circumscribing), according to the plan documents
51	Gross volume building total	$GV_{building} = GV_{basement} + GV_{eaves} + GV_{roof}$	m³	Gross volume of the building, according to the plan documents
52	V concrete	$V_{concrete}$	m³	Volume of concrete according to the plan documents
53	V screed concrete	V_{screed}	m³	Volume of screed concrete according to the plan documents
54	V reinforced concrete	$V_{reinforced}$	m³	Volume of reinforced concrete according to the plan documents
55	V steel	V_{steel}	m³	Volume of steel according to the plan documents
56	V full brick work	$V_{fullbrick}$	m³	Volume of full brick work according to the plan documents
57	V hollow brick work	$V_{hollowbrick}$	m³	Volume of hollow brick work according to the plan documents
58	V sand, gravel, stone	V_{gravel}	m³	Volume of sand, gravel, stone according to the plan documents
59	V wood	V_{wood}	m³	Volume of wood according to the plan documents
60	V mineral wool	V_{mw}	m³	Volume of mineral wool (MW) according to the plan documents
61	V polystyrene	V_{ps}	m³	Volume of polystyrene (PS) according to the plan documents
62	V gypsum	V_{gypsum}	m³	Volume of gypsum according to the plan documents
63	Total fenestration area	$A_{windows}$	m²	Total fenestration area according to the plan documents
64	Wall area excluding fenestration area	A_{wall}	m²	Wall area excluding fenestration area according to the plan documents
65	Density concretes	$\rho_{concrete}$	t/m³ material	Volumetric mass density of concretes based on literature values
66	Mass content of steel in reinforced concrete	$c_{steel\text{-}concrete}$	t/m³ material	Mass content of steel in reinforced concrete based on literature values
67	Density steel	ρ_{steel}	t/m³ material	Volumetric mass density of steel based on literature values
68	Density fullbrick wall (incl. mortar and plaster)	$\rho_{fullbrick}$	t/m³ material	Volumetric mass density of full brick wall (incl. mortar and plaster) based on literature values
69	Density hollow brick wall (incl. mortar and plaster)	$\rho_{hollowbrick}$	t/m³ material	Volumetric mass density of hollow brick wall (incl. mortar and plaster) based on literature values
70	Density mineral fill	ρ_{gravel}	t/m³ material	Volumetric mass density of mineral fill based on literature values
71	Density wood	ρ_{wood}	t/m³ material	Volumetric mass density of wood based on literature values
72	Density mineral wool	ρ_{mw}	t/m³ material	Volumetric mass density of mineral wool based on literature values
73	Density poly-styrene	ρ_{ps}	t/m³ material	Volumetric mass density of poly-styrene based on literature values
74	Density gypsum	ρgypsum	t/m³ material	Volumetric mass density of gypsum based on literature values
75	Area density glass	$\rho_{A,glass}$	t/m² material	Area mass density of glass based on literature values
76	Mass concrete	$m_{concrete} = V_{(concrete+reinforced)}*\rho_{concrete}$	t	Calculated mass concrete
77	Mass steel	$m_{steel} = (V_{reinforced}*c_{reinforced\text{-}steel}+V_{steel})*\rho_{steel}$	t	Calculated mass steel
78	Mass brickwork	$m_{brickwork} = V_{fullbrick}*\rho_{fullbrick}+V_{hollowbrick}*\rho_{fullbrick}$	t	Calculated mass brickwork
79	Mass gravel (mineral fill)	$m_{gravel} = V_{gravel}*\rho_{gravel}$	t	Calculated mass gravel (mineral fill)
80	Mass wood	$m_{wood} = V_{wood}*\rho_{wood}$	t	Calculated mass wood
81	Mass mineral wool	$m_{mw} = V_{mw}*\rho_{mw}$	t	Calculated mass mineral wool
82	Mass poly-styrene	$m_{ps} = Vy*\rho y$	t	Calculated mass polystyrene
83	Mass gypsum	$m_{gypsum} = V_{gypsum}*\rho_{gypsum}$	t	Calculated mass gypsum
84	Mass glass	$m_{gypsum} = A_{windows}*\rho_{A,window}$	t	Calculated mass glass
85	Mass total	$m_{total}=\Sigma m_m$	t	Calculated mass total
86	MI concrete per $GV_{building}$	$MI_{building,concrete} = m_{concrete} / GV_{building}$	t/m³ GV	Calculated material intensity MI of concrete per unit of gross volume of the total building
87	MI steel per $GV_{building}$	$MI_{building,steel} = m_{steel} / GV_{building}$	t/m³ GV	Calculated material intensity MI of steel per unit of gross volume of the total building
88	MI brickwork per $GV_{building}$	$MI_{building,brickwork} = m_{brickwork} / GV_{building}$	t/m³ GV	Calculated material intensity MI of brickwork per unit of gross volume of the total building
89	MI gravel per $GV_{building}$	$MI_{building,gravel} = m_{gravel} / GV_{building}$	t/m³ GV	Calculated material intensity MI of gravel per unit of gross volume of the total building

No.	Parameter	Symbol	Unit	Description
90	MI wood per $GV_{building}$	$MI_{building,wood} = m_{wood} / GV_{building}$	t/m³ GV	Calculated material intensity MI of wood per unit of gross volume of the total building
91	MI mineral wool per $GV_{building}$	$MI_{building,MW} = m_{MW} / GV_{building}$	t/m³ GV	Calculated material intensity MI of mineral wool per unit of gross volume of the total building
92	MI PS per $GV_{building}$	$MI_{building,PS} = m_{PS} / GV_{building}$	t/m³ GV	Calculated material intensity MI of PS per unit of gross volume of the total building
93	MI gypsum per $GV_{building}$	$MI_{building,gypsum} = m_{gypsum} / GV_{building}$	t/m³ GV	Calculated material intensity MI of gypsum per unit of gross volume of the total building
94	MI glass per $GV_{building}$	$MI_{building,glass} = m_{glass} / GV_{building}$	t/m³ GV	Calculated material intensity MI of glass per unit of gross volume of the total building
95	MI total per $GV_{building}$	$MI_{building,total} = m_{total} / GV_{building}$	t/m³ GV	Calculated material intensity MI of total per unit of gross volume of the total building
96	MI concrete per GV_{eaves}	$MI_{eaves,concrete} = m_{concrete} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of concrete per unit of gross volume of the building from the surface up to the eaves
97	MI steel per GV_{eaves}	$MI_{eaves,steel} = m_{steel} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of steel per unit of gross volume of the building from the surface up to the eaves
98	MI brickwork per GV_{eaves}	$MI_{eaves,brickwork} = m_{brickwork} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of brickwork per unit of gross volume of the building from the surface up to the eaves
99	MI gravel per GV_{eaves}	$MI_{eaves,gravel} = m_{gravel} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of gravel per unit of gross volume of the building from the surface up to the eaves
100	MI wood per GV_{eaves}	$MI_{eaves,wood} = m_{wood} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of wood per unit of gross volume of the building from the surface up to the eaves
101	MI mineral wool per GV_{eaves}	$MI_{eaves,MW} = m_{MW} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of mineral w. per unit of gross volume of the building from the surface up to the eaves
102	MI PS per GV_{eaves}	$MI_{eaves,PS} = m_{PS} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of PS per unit of gross volume of the building from the surface up to the eaves
103	MI gypsum per GV_{eaves}	$MI_{eaves,gypsum} = m_{gypsum} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of gypsum per unit of gross volume of the building from the surface up to the eaves
104	MI glass per GV_{eaves}	$MI_{eaves,glass} = m_{glass} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of glass per unit of gross volume of the building from the surface up to the eaves
105	MI total per GV_{eaves}	$MI_{eaves,total} = m_{total} / GV_{eaves}$	t/m³ GV	Calculated material intensity MI of total per unit of gross volume of the building from the surface up to the eaves
106	MI concrete per GV_{AGL}	$MI_{AGL,concrete} = m_{concrete} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of concrete per unit of gross volume of the building from the surface up to the ridge
107	MI steel per GV_{AGL}	$MI_{AGL,steel} = m_{steel} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of steel per unit of gross volume of the building from the surface up to the ridge
108	MI brickwork per GV_{AGL}	$MI_{AGL,brickwork} = m_{brickwork} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of brickwork per unit of gross volume of the building from the surface up to the ridge
109	MI gravel per GV_{AGL}	$MI_{AGL,gravel} = m_{gravel} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of gravel per unit of gross volume of the building from the surface up to the ridge
110	MI wood per GV_{AGL}	$MI_{AGL,wood} = m_{wood} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of wood per unit of gross volume of the building from the surface up to the ridge
111	MI mineral wool per GV_{AGL}	$MI_{AGL,MW} = m_{MW} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of mineral w. per unit of gross volume of the building from the surface up to the ridge
112	MI PS per GV_{AGL}	$MI_{AGL,PS} = m_{PS} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of PS per unit of gross volume of the building from the surface up to the ridge
113	MI gypsum per GV_{AGL}	$MI_{AGL,gypsum} = m_{gypsum} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of gypsum per unit of gross volume of the building from the surface up to the ridge
114	MI glass per GV_{AGL}	$MI_{AGL,glass} = m_{glass} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of glass per unit of gross volume of the building from the surface up to the ridge
115	MI total per GV_{AGL}	$MI_{AGL,total} = m_{total} / GV_{AGL}$	t/m³ GV	Calculated material intensity MI of total per unit of gross volume of the building from the surface up to the ridge
116	MI concrete per $NFA_{conditioned}$	$MI_{NFAcond,concrete} = m_{concrete} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of concrete per unit of conditioned net floor area of the building
117	MI steel per $NFA_{conditioned}$	$MI_{NFAcond,steel} = m_{steel} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of steel per unit of conditioned net floor area of the building
118	MI brickwork per $NFA_{conditioned}$	$MI_{NFAcond,brickwork} = m_{brickwork} / NFA_{cond\ d}$	t/m² NFA	Calculated material intensity MI of brickwork per unit of conditioned net floor area of the building
119	MI gravel per $NFA_{conditioned}$	$MI_{NFAcond,gravel} = m_{gravel} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of gravel per unit of conditioned net floor area of the building
120	MI wood per $NFA_{conditioned}$	$MI_{NFAcond,wood} = m_{wood} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of wood per unit of conditioned net floor area of the building
121	MI mineral wool per $NFA_{conditioned}$	$MI_{NFAcond,MW} = m_{MW}\ NFA_{cond}$	t/m² NFA	Calculated material intensity MI of mineral w. per unit of conditioned net floor area of the building
122	MI PS per $NFA_{conditioned}$	$MI_{NFAcond,PS} = m_{PS} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of PS per unit of conditioned net floor area of the building
123	MI gypsum per $NFA_{conditioned}$	$MI_{NFAcond,gypsum} = m_{gypsum} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of gypsum per unit of conditioned net floor area of the building
124	MI glass per $NFA_{conditioned}$	$MI_{NFAcond,glass} = m_{glass} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of glass per unit of conditioned net floor area of the building
125	MI total per $NFA_{conditioned}$	$MI_{NFAcond,total} = m_{total} / NFA_{cond}$	t/m² NFA	Calculated material intensity MI of total per unit of conditioned net floor area of the building
126	Number or floors (incl. basement, excl. unused attic)	Number		Number of floors
127	Mean value floor height of all floors	$h = \Sigma h_i / n$	m	Mean value of the floor height of all floors
128	Average floor height of above-ground level floors	$h = \Sigma h_i / n$	m	Mean value of the floor height of all floors above ground level
129	Conversion factor $GV_{building}$ / $NFA_{conditioned}$	$CF = GV_{building} / NFA_{conditioned}$	[-]	Conversion factor between the total gross volume and the total net floor area conditioned of the building
130	Conversion factor $GV_{eaves}/NFA_{conditioned}$	$CF = GV_{eaves} / NFA_{conditioned}$	[-]	Conversion factor between the gross volume eaves and the total net floor area conditioned of the building
131	Conversion factor ratio GV_{ridge}/GFA_p	$CF = GV_{ridge}/GFA_p$	[-]	Conversion factor between the gross volume of the ridge roof and gross floor area per floor (equals the ground area)

3 Results

3.1 The population and the sample

Table S7 Number of objects in the reduced sample by age-category, use-category, and size-category. Refers to table 3.1.1.2 in the supporting_data_2, sheet 3-1.

No.	Object categories	3.1.1.2 Number of the reduced population of objects (part of buildings) (N=226,428)						
	use categories	object age categories						
	size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	*36,775*	*1,470*	*576*	*2,073*	*2,428*	*2,330*	*45,652*
0.1	<1000 m³	21,040	806	350	1,354	1,627	1,385	26,562
0.2	1000-5000 m³	10,531	513	159	584	627	756	13,170
0.3	>5000 m³	5,204	151	67	135	174	189	5,920
1	*residential*	*2,915*	*33,102*	*14,833*	*39,616*	*26,481*	*14,234*	*131,181*
1.1	<1000 m³	1,133	8,826	10,766	23,318	16,708	9,612	70,363
1.2	1000-5000 m³	1,069	15,844	3,215	11,905	7,899	3,647	43,579
1.3	>5000 m³	713	8,432	852	4,393	1,874	975	17,239
2	*service*	*1,635*	*8,275*	*1,517*	*7,022*	*10,547*	*5,451*	*34,447*
2.1	<1000 m³	1,120	3,248	824	3,550	4,639	2,391	15,772
2.2	1000-5000 m³	377	3,112	550	2,572	4,023	2,040	12,674
2.3	>5000 m³	138	1,915	143	900	1,885	1,020	6,001
3	*industrial*	*1,936*	*2,701*	*1,125*	*4,435*	*4,099*	*852*	*15,148*
3.1	<1000 m³	1,571	1,615	678	2,351	1,644	364	8,223
3.2	1000-5000 m³	326	872	317	1,496	1,578	328	4,917
3.3	>5000 m³	39	214	130	588	877	160	2,008
Σ	**all objects (total)**	**43,261**	**45,548**	**18,051**	**53,146**	**43,555**	**22,867**	**226,428**

Table S8 GV_{eaves} of objects in the reduced sample by age-category, use-category, and size-category. Refers to table 3.1.2.2 in the supporting_data_2, sheet 3-1.

No.	Object categories	3.1.1.2 Number of the reduced population of objects (part of buildings) (N=226,428)						
	use categories	object age categories						
	size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	101,957,707	3,321,293	1,402,320	3,532,750	4,839,095	4,938,093	119,991,258
0.1	<1000 m³	10,873,908	414,842	180,630	689,861	874,885	720,161	13,754,288
0.2	1000-5000 m³	24,318,100	1,176,454	310,415	1,137,757	1,263,646	1,580,662	29,787,034
0.3	>5000 m³	66,765,699	1,729,997	911,275	1,705,131	2,700,564	2,637,270	76,449,936
1	*residential*	9,369,904	115,858,475	21,176,762	81,732,879	44,565,072	22,462,450	295,165,542
1.1	<1000 m³	589,395	4,922,369	5,039,963	12,359,380	8,827,524	4,758,024	36,496,655
1.2	1000-5000 m³	3,007,366	43,331,177	7,420,467	29,665,809	17,624,393	7,897,123	108,946,335
1.3	>5000 m³	5,773,143	67,604,929	8,716,332	39,707,690	18,113,155	9,807,303	149,722,552
2	*service*	3,050,597	35,130,854	3,283,843	18,693,059	40,675,808	21,546,316	122,380,479
2.1	<1000 m³	536,890	1,758,312	440,219	1,875,423	2,468,620	1,287,924	8,367,387
2.2	1000-5000 m³	753,704	7,260,196	1,194,212	5,770,208	9,315,157	4,722,013	29,015,489
2.3	>5000 m³	1,760,004	26,112,347	1,649,412	11,047,429	28,892,032	15,536,379	84,997,602
3	*industrial*	1,746,003	5,339,049	2,853,658	13,943,582	19,540,404	3,960,481	47,383,177
3.1	<1000 m³	726,727	823,314	343,435	1,212,785	870,620	194,230	4,171,111
3.2	1000-5000 m³	588,288	1,771,692	682,874	3,121,004	3,828,284	785,762	10,777,904
3.3	>5000 m³	430,988	2,744,042	1,827,349	9,609,793	14,841,500	2,980,489	32,434,162
Σ	**all objects (total)**	**116,124,212**	**159,649,670**	**28,716,584**	**117,902,271**	**109,620,378**	**52,907,341**	**584,920,457**

3.1.1 Spatial distribution of samples and sample size

Table S9 Number of objects in the sample (table 3.1.1.1) and therein contained full buildings (table 3.1.1.3) in the reduced sample by age-category, use-category, and size-category. Refers to tables 3.1.1.1 and 3.1.1.3 in the supporting_data_2, sheet 3-1.

		3.1.1.1 Number of sampled objects (part of buildings) (N=256)							**3.1.1.3 Number of sampled objects (full buildings) (N=207)**						
	object use categories	object age categories							building age categories						
	object size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	*8*	*5*	*4*	*6*	*6*	*3*	*32*	*7*	*2*	*4*	*5*	*5*	*2*	*25*
0.1	<1000 m³	5	2	1	3	3	1	15	4	0	1	2	2	0	9
0.2	1000-5000 m³	1	2	2	2	2	1	10	1	2	2	2	2	1	10
0.3	>5000 m³	2	1	1	1	1	1	7	2	0	1	1	1	1	6
1	*residential*	*4*	*40*	*18*	*43*	*32*	*17*	*154*	0	34	*16*	*36*	*26*	*14*	*126*
1.1	<1000 m³	1	11	12	25	19	4	72	0	6	11	22	16	3	58
1.2	1000-5000 m³	1	24	4	14	11	12	66	0	24	3	10	8	10	55
1.3	>5000 m³	2	5	2	4	2	1	16	0	4	2	4	2	1	13
2	*service*	*3*	*10*	*4*	*6*	*11*	*7*	*41*	*2*	*9*	*3*	*4*	*6*	*5*	*29*
2.1	<1000 m³	1	3	1	4	3	4	16	0	3	0	2	1	3	9
2.2	1000-5000 m³	1	4	2	1	7	2	17	1	3	2	1	4	1	12
2.3	>5000 m³	1	3	1	1	1	1	8	1	3	1	1	1	1	8
3	*industrial*	*4*	*5*	*5*	*6*	*5*	*4*	*29*	*3*	*5*	*5*	*5*	*5*	*4*	*27*
3.1	<1000 m³	1	2	2	2	2	1	10	1	2	2	2	2	1	10
3.2	1000-5000 m³	1	1	2	2	1	1	8	0	1	2	1	1	1	6
3.3	>5000 m³	2	2	1	2	2	2	11	2	2	1	2	2	2	11
Σ	**all objects (total)**	**19**	**60**	**31**	**61**	**54**	**31**	**256**	**12**	**50**	**28**	**50**	**42**	**25**	**207**

Table S10 Sample size of objects in the sample based on the number of objects (table 3.1.3.1) and the GV_{eaves} of objects (table 3.1.3.2) by age-category, use-category, and size-category. Refers to tables 3.1.3.1 and 3.1.3.2 in the supporting_data_2, sheet 3-1.

		3.1.3.1 Sample size related to the reduced population based on no of objects (N=256)							**3.1.3.2 Sample size related to the reduced population based on GV_{eaves} of objects (N=256)**						
	object use categories	object age categories							object age categories						
	object size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information (total)*	*0.02%*	*0.34%*	*0.69%*	*0.29%*	*0.25%*	*0.13%*	*0.07%*	*0.27%*	*0.58%*	*1.49%*	*0.61%*	*0.47%*	*0.27%*	*0.31%*
0.1	<1000 m³	0.02%	0.25%	0.29%	0.22%	0.18%	0.07%	0.06%	0.03%	0.17%	0.14%	0.29%	0.13%	0.05%	0.06%
0.2	1000-5000 m³	0.01%	0.39%	1.26%	0.34%	0.32%	0.13%	0.08%	0.01%	0.44%	1.71%	0.38%	0.33%	0.16%	0.08%
0.3	>5000 m³	0.04%	0.66%	1.49%	0.74%	0.57%	0.53%	0.12%	0.41%	0.76%	1.69%	0.88%	0.64%	0.39%	0.45%
1	*residential (total)*	*0.14%*	*0.12%*	*0.12%*	*0.11%*	*0.12%*	*0.12%*	*0.12%*	*0.32%*	*0.12%*	*0.20%*	*0.10%*	*0.14%*	*0.17%*	*0.13%*
1.1	<1000 m³	0.09%	0.12%	0.11%	0.11%	0.11%	0.04%	0.10%	0.10%	0.13%	0.10%	0.11%	0.12%	0.05%	0.10%
1.2	1000-5000 m³	0.09%	0.15%	0.12%	0.12%	0.14%	0.33%	0.15%	0.04%	0.16%	0.10%	0.13%	0.16%	0.26%	0.15%
1.3	>5000 m³	0.28%	0.06%	0.23%	0.09%	0.11%	0.10%	0.09%	0.49%	0.09%	0.36%	0.08%	0.13%	0.15%	0.13%
2	*service (total)*	*0.18%*	*0.12%*	*0.26%*	*0.09%*	*0.10%*	*0.13%*	*0.12%*	*0.73%*	*0.11%*	*0.97%*	*0.13%*	*0.07%*	*0.10%*	*0.14%*
2.1	<1000 m³	0.09%	0.09%	0.12%	0.11%	0.06%	0.17%	0.10%	0.09%	0.09%	0.11%	0.08%	0.08%	0.21%	0.10%
2.2	1000-5000 m³	0.27%	0.13%	0.36%	0.04%	0.17%	0.10%	0.13%	0.60%	0.12%	0.34%	0.04%	0.15%	0.09%	0.13%
2.3	>5000 m³	0.72%	0.16%	0.70%	0.11%	0.05%	0.10%	0.13%	0.98%	0.11%	1.65%	0.19%	0.05%	0.10%	0.14%
3	*industrial (total)*	*0.21%*	*0.19%*	*0.44%*	*0.14%*	*0.12%*	*0.47%*	*0.19%*	*2.72%*	*0.68%*	*0.58%*	*0.21%*	*0.12%*	*4.43%*	*0.69%*
3.1	<1000 m³	0.06%	0.12%	0.29%	0.09%	0.12%	0.27%	0.12%	0.12%	0.15%	0.30%	0.11%	0.14%	0.32%	0.15%
3.2	1000-5000 m³	0.31%	0.11%	0.63%	0.13%	0.06%	0.30%	0.16%	0.32%	0.08%	0.53%	0.14%	0.03%	0.25%	0.14%
3.3	>5000 m³	5.13%	0.93%	0.77%	0.34%	0.23%	1.25%	0.55%	10.40%	1.23%	0.64%	0.24%	0.15%	5.79%	0.95%
Σ	**all objects (total)**	**0.04%**	**0.13%**	**0.17%**	**0.11%**	**0.12%**	**0.14%**	**0.11%**	**0.32%**	**0.14%**	**0.39%**	**0.13%**	**0.13%**	**0.47%**	**0.22%**

Table S11 Share of the GV_{eaves} of full buildings related to the GV_{eaves} of objects. Refers to table 3.1.2.4 in the supporting_data_2, sheet 3-1.

No.	Object categories	3.1.2.4 Share GV_{eaves} of full buildings related to the GV_{eaves} of objects in %						
	use categories	object age categories						
	size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	100%	27%	100%	96%	99%	97%	96%
0.1	<1000 m³	73%	0%	100%	55%	78%	0%	60%
0.2	1000-5000 m³	100%	100%	100%	100%	100%	100%	100%
0.3	>5000 m³	100%	0%	100%	100%	100%	100%	96%
1	*residential*	0%	92%	93%	86%	87%	91%	83%
1.1	<1000 m³	0%	61%	94%	91%	86%	84%	83%
1.2	1000-5000 m³	0%	100%	62%	72%	76%	86%	85%
1.3	>5000 m³	0%	85%	100%	100%	100%	100%	80%
2	*service*	98%	97%	98%	97%	84%	82%	93%
2.1	<1000 m³	0%	100%	0%	56%	24%	65%	53%
2.2	1000-5000 m³	100%	86%	100%	100%	76%	28%	80%
2.3	>5000 m³	100%	100%	100%	100%	100%	100%	100%
3	*industrial*	96%	100%	100%	96%	100%	100%	99%
3.1	<1000 m³	100%	100%	100%	100%	100%	100%	100%
3.2	1000-5000 m³	0%	100%	100%	73%	100%	100%	79%
3.3	>5000 m³	100%	100%	100%	100%	100%	100%	100%
Σ	**all objects (total)**	91%	88%	97%	91%	90%	97%	92%

3.1.2 Re-categorization of sampled objects after analyzing plan documents

Table S12 Updated number of objects after analyzing the plan documents (re-categorization). Refers to table 3.1.4.1 in the supporting_data_2, sheet 3-1.

No.	Object categories	3.1.4.1 Number of sampled objects (part of buildings) after re-categorization (N=256)						
	use categories	object age categories						
	size categories	no info	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	-	-	-	-	-	-	-
0.1	<1000 m³	-	-	-	-	-	-	-
0.2	1000-5000 m³	-	-	-	-	-	-	-
0.3	>5000 m³	-	-	-	-	-	-	-
1	*residential*	-	46	21	54	36	34	191
1.1	<1000 m³	-	11	14	29	19	12	85
1.2	1000-5000 m³	-	27	4	18	13	17	79
1.3	>5000 m³	-	8	3	7	4	5	27
2	*service*	-	6	2	6	14	11	39
2.1	<1000 m³	-	2	-	4	6	5	17
2.2	1000-5000 m³	-	2	2	1	7	3	15
2.3	>5000 m³	-	2	-	1	1	3	7
3	*industrial*	-	2	8	4	4	8	26
3.1	<1000 m³	-	2	4	2	1	2	11
3.2	1000-5000 m³	-	-	2	2	1	2	7
3.3	>5000 m³	-	-	2	-	2	4	8
Σ	**all objects (total)**	-	54	31	64	54	53	256

3.2 Building dimensions

3.2.1 Story height

Table S13 Floor-height of buildings in m considering only above-ground level floors (table 3.2.1.1) & all floors (table 3.2.1.2). Refers to table 3.2.1.1 and 3.2.1.2 in the supporting_data_2, sheet 3-1.

		3.2.1.1 Floor height h_p above ground level floors of full buildings (N=207)						**3.2.1.2 Floor height h_p for all floors of full buildings (N=207)**					
	object use categories	building age categories						building age categories					
	object size categories	<1919	1919-1945	1946-1976	1977-1996	>1996	total	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	3.41	2.83	2.83	2.88	2.96	3.01	3.53	2.97	2.94	2.95	2.96	3.10
0.1	<1000 m³	3.01	2.69	2.76	2.78	2.86	2.79	3.28	2.86	2.91	2.91	2.91	2.94
0.2	1000-5000 m³	3.46	2.79	2.88	2.89	2.93	3.12	3.56	2.90	2.98	2.88	2.89	3.17
0.3	>5000 m³	3.59	3.50	2.93	3.38	3.38	3.32	3.67	3.58	2.95	3.38	3.40	3.37
1	*residential*	3.95	3.65	3.28	4.80	3.85	3.96	4.05	3.65	3.28	5.06	3.89	4.06
1.1	<1000 m³	4.38		3.20	4.30	3.93	3.83	4.38		3.20	4.30	3.97	3.84
1.2	1000-5000 m³	3.20	3.65	3.40	5.12	3.52	4.14	3.55	3.65	3.40	5.50	3.54	4.33
1.3	>5000 m³	3.89	0.00	3.40	4.04	3.98	3.88	3.99	0.00	3.40	4.04	4.04	3.93
2	*service*	3.85	3.74	3.77	4.95	5.55	4.51	3.85	3.79	4.16	4.95	5.55	4.58
2.1	<1000 m³	3.85	3.77	3.30	4.00	4.00	3.76	3.85	3.77	3.88	4.00	4.00	3.88
2.2	1000-5000 m³		4.00	4.72	4.60	3.70	4.20		4.17	4.72	4.60	3.70	4.27
2.3	>5000 m³		3.45		5.60	6.78	5.65		3.45		5.60	6.78	5.65
3	*industrial*	3.48	3.10	2.93	3.39	3.59	3.30	3.60	3.22	3.05	3.48	3.60	3.39
3.1	<1000 m³	3.41	2.83	2.83	2.88	2.96	3.01	3.53	2.97	2.94	2.95	2.96	3.10
3.2	1000-5000 m³	3.01	2.69	2.76	2.78	2.86	2.79	3.28	2.86	2.91	2.91	2.91	2.94
3.3	>5000 m³	3.46	2.79	2.88	2.89	2.93	3.12	3.56	2.90	2.98	2.88	2.89	3.17
Σ	**all objects (total)**	3.59	3.50	2.93	3.38	3.38	3.32	3.67	3.58	2.95	3.38	3.40	3.37

3.2.2 Conversion factors

Table S14 Conversion factor between gross floor area and net floor area total (table 3.2.2.1) & conditioned (table 3.2.2.2). Refers to table 3.2.2.1 & 3.2.2.2 in the supporting_data_2, sheet 3-1.

		3.2.2.1 Conversion factor CF NFA_{total}/GFA of full buildings (N=207)						**3.2.2.2 Conversion factor CF $NFA_{conditioned}$/GFA of full buildings (N=207)**					
	object use categories	building age categories						building age categories					
	object size categories	<1919	1919-1945	1946-1976	1977-1996	>1996	total	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	53%	50%	59%	55%	55%	55%	76%	81%	83%	81%	80%	80%
0.1	<1000 m³	55%	56%	50%	54%	59%	54%	78%	78%	79%	79%	78%	79%
0.2	1000-5000 m³	54%	60%	58%	51%	53%	54%	78%	79%	81%	77%	76%	78%
0.3	>5000 m³	51%	48%	61%	60%	58%	55%	75%	82%	84%	86%	84%	81%
1	*residential*	60%	45%	63%	69%	87%	81%	75%	77%	92%	90%	95%	93%
1.1	<1000 m³	83%		79%	94%	60%	72%	83%		79%	94%	73%	78%
1.2	1000-5000 m³	44%	45%	64%	50%	66%	53%	83%	77%	82%	90%	86%	86%
1.3	>5000 m³	62%		62%	86%	88%	84%	73%		93%	89%	96%	94%
2	*service*	46%	15%	62%	81%	72%	51%	62%	78%	87%	81%	72%	76%
2.1	<1000 m³	46%	61%	60%	83%	32%	51%	62%	61%	77%	83%	53%	64%
2.2	1000-5000 m³		36%	64%	95%	98%	49%		39%	95%	95%	98%	56%
2.3	>5000 m³		8%		80%	72%	51%		89%		80%	72%	79%
3	*industrial*	53%	37%	59%	60%	76%	61%	76%	80%	84%	83%	87%	83%
3.1	<1000 m³	53%	50%	59%	55%	55%	55%	76%	81%	83%	81%	80%	80%
3.2	1000-5000 m³	55%	56%	50%	54%	59%	54%	78%	78%	79%	79%	78%	79%
3.3	>5000 m³	54%	60%	58%	51%	53%	54%	78%	79%	81%	77%	76%	78%
Σ	**all objects (total)**	51%	48%	61%	60%	58%	55%	75%	82%	84%	86%	84%	81%

3.3 Material intensities of the sampled objects and buildings

Table S15 Material intensities MI_{total} in t/m³ GV_{eaves} for objects, based on classification according to the DBM (3.3.1.1) and in t/m³ $GV_{building}$ for buildings based on the classification according to the plan documents (3.3.1.2). Refers to table 3.3.1.1 and 3.3.1.2 in the supporting_data_2, sheet 3-1.

		3.3.1.1 MI_{total} in t/m³ GV_{eaves} of objects (N=256)							**3.3.1.2 MI_{total} in t/m³ $GV_{building}$ of full buildings (N=207)**					
	object use categories	building age categories							building age categories					
	object size categories		<1919	1919-1945	1946-1976	1977-1996	>1996	total	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*	*0.38*	*0.52*	*0.83*	*0.59*	*0.72*	*0.57*	*0.58*						
0.1	<1000 m³	0.37	0.45	1.22	0.54	0.67	0.52	0.54						
0.2	1000-5000 m³	0.70	0.51	0.75	0.67	0.86	0.52	0.68						
0.3	>5000 m³	0.26	0.69	0.61	0.58	0.55	0.65	0.51						
1	*residential*	*0.68*	0.58	*0.54*	*0.86*	*0.77*	*0.73*	*0.71*	0.39	*0.36*	*0.45*	*0.46*	*0.44*	*0.43*
1.1	<1000 m³	0.77	0.80	0.57	1.04	0.83	0.82	0.86	0.49	0.35	0.48	0.49	0.38	0.45
1.2	1000-5000 m³	0.47	0.51	0.55	0.60	0.71	0.72	0.60	0.37	0.38	0.42	0.44	0.48	0.41
1.3	>5000 m³	0.73	0.47	0.34	0.61	0.47	0.56	0.53	0.37	0.36	0.42	0.41	0.45	0.40
2	*service*	*0.44*	*0.48*	*0.87*	*0.62*	*0.46*	*0.45*	*0.52*	*0.38*	*0.36*	*0.36*	*0.41*	*0.40*	*0.39*
2.1	<1000 m³	0.67	0.29	1.62	0.74	0.29	0.49	0.56	0.26		0.39	0.37	0.51	0.40
2.2	1000-5000 m³	0.33	0.51	0.59	0.33	0.54	0.38	0.50	0.43	0.36	0.28	0.42	0.38	0.39
2.3	>5000 m³	0.31	0.62	0.68	0.42	0.38	0.42	0.51	0.47		0.33	0.38	0.30	0.36
3	*industrial*	*0.29*	*0.47*	*0.46*	*0.50*	*0.34*	*0.37*	*0.41*	*0.25*	*0.40*	*0.44*	*0.23*	*0.27*	*0.32*
3.1	<1000 m³	0.20	0.35	0.61	0.71	0.49	0.49	0.50	0.25	0.46	0.49	0.18	0.37	0.38
3.2	1000-5000 m³	0.46	0.66	0.43	0.30	0.18	0.38	0.39		0.32	0.34	0.18	0.38	0.31
3.3	>5000 m³	0.25	0.50	0.20	0.50	0.27	0.31	0.35		0.41		0.27	0.20	0.27

Table S16 Material intensities MI_{PS+MW} in t/m³ $GV_{building}$ for polystyrene (PS) and mineral wool (MW) for full buildings, based on classification according to the plan documents. Refers to table 3.3.1.3 in the supporting_data_2, sheet 3-1.

		3.3.1.3 MI_{PS+MW} in kg/m³ $GV_{building}$ of full buildings (N=207)					
	object use categories	building age categories					
	object size categories	<1919	1919-1945	1946-1976	1977-1996	>1996	total
0	*no information*						
0.1	<1000 m³						
0.2	1000-5000 m³						
0.3	>5000 m³						
1	*residential*	0.51	*0.56*	*0.47*	*0.85*	*1.25*	*0.69*
1.1	<1000 m³	0.18	0.54	0.42	1.00	2.14	0.76
1.2	1000-5000 m³	0.62	0.80	0.56	0.72	0.93	0.69
1.3	>5000 m³	0.41	0.44	0.44	0.52	0.39	0.44
2	*service*	*0.68*	*0.49*	*0.14*	*0.79*	*1.06*	*0.70*
2.1	<1000 m³	1.04		0.15	0.64	1.52	0.86
2.2	1000-5000 m³	0.46	0.49	-	0.84	0.67	0.61
2.3	>5000 m³	0.42		0.26	0.74	0.86	0.63
3	*industrial*	-	*0.37*	*0.90*	*0.18*	*0.75*	*0.49*
3.1	<1000 m³	-	0.46	-	-	0.66	0.27
3.2	1000-5000 m³		0.26	2.69	0.52	1.52	1.05
3.3	>5000 m³		0.35		0.11	0.60	0.41

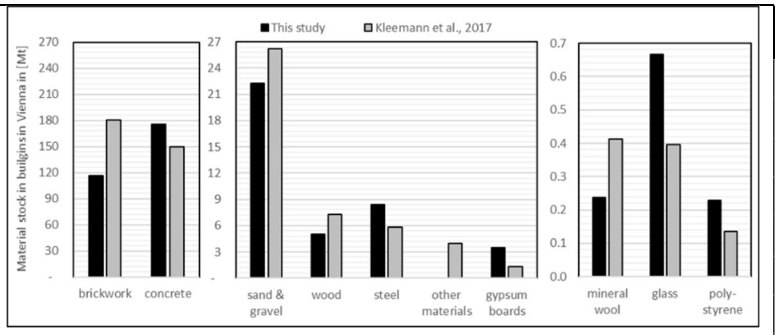
Table S17 Material intensities MI_{total} in t/m³ $GV_{building}$ for this study (buildings in Vienna, based on based on classification according to the plan document) and buildings in Germany (Schiller et al. 2019). Refers to table 3.3.3.3 in the supporting_data_2, sheet 3-1.

Residential building type	Location	concrete	brickwork	sand & gravel	other minerals	steel	wood	fossil / PS	glass
single-family (in Vienna 250-1,000 m³ GV_{eaves})	Vienna	0.247	0.147	0.032	0.006	0.013	0.007	0.000	0.001
	Germany	0.203	0.046	0.033	0.207	0.020	0.011	0.001	0.001
multi-family small (in Vienna 1,000-5,000 m³ GV_{eaves})	Vienna	0.207	0.149	0.028	0.005	0.009	0.007	0.000	0.001
	Germany	0.213	0.093	0.024	0.121	0.023	0.005	0.001	0.001
multi-family large (in Vienna >5,000 m³ GV_{eaves})	Vienna	0.150	0.197	0.026	0.003	0.006	0.001	0.000	0.001
	Germany	0.348	0.000	0.006	0.022	0.038	0.001	0.000	0.001

3.4 Material stock of buildings in Vienna based on new material intensities

Table S18 Material stocks MS_m for materials m for this study and Kleemann et al. (2017). Refers to supporting_data_3, sheet Results. Showing also Figure 7 from the manuscript.

material	This study	Kleemann et al. 2017
brickwork	116,423,638	180,031,920
concrete	175,323,976	149,477,317
sand & gravel	22,242,401	26,182,195
wood	5,009,007	7,289,269
steel	8,385,538	5,788,185
other materials	not counted	3,983,785
gypsum boards	3,445,566	1,336,587
mineral wool	237,209	412,040
glass	665,852	396,241
poly- styrene	228,334	136,189
total	331,961,523	375,033,727



4 Discussion

Table S19 shows the comparison of the results of the material stock estimates between a study that used the data as presented in this article (Lederer et al. submitted), compared to the values of Kleemann et al. (2017). The values in this table correspond to Figure 6 in the article.

Table S19 Comparison of the total material stock estimate for buildings in Vienna in 2014 from Lederer et al. (submitted) who used the DBM and material intensity data presented in this article, and for Kleemann et al. (2017). Values are given in tons.

material	**Lederer et al. submitted [t]**	**Kleemann et al. 2017 [t]**
brickwork	124,176,505	180,031,920
concrete	161,021,586	149,477,317
sand & gravel	20,529,373	26,182,195
wood	3,221,533	7,289,269
steel	8,477,050	5,788,185
other materials	not determined	3,983,785
gypsum boards	3,445,566	1,336,587
mineral wool	260,626	412,040
glass	647,668	396,241

poly- styrene	364,024	136,189
total	**322,143,932**	**375,033,727**

5 Conclusions

References

ASI. 2011. Eurocode 1: Einwirkungen auf Tragwerke - Teil 1-1: Allgemeine Einwirkungen - Wichten, Eigengewicht und Nutzlasten im Hochbau (Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings). Vienna: Austrian Standards Institute (ASI).

Baumeister, L. 1955. *Preisermittlung und Veranschlagen von Hoch-, Tief- und Stahlbetonbauten : ein Hilfs- und Nachschlagebuch zum Veranschlagen von Erd-, Straßen-, Wasser-, Brücken-, Stahlbeton-, Mauerer- und Zimmererarbeiten*. 11., neubearb. Aufl.. ed. Berlin [u.a.]: Berlin [u.a.] : Springer.

Gruber, E., R. Gutmann, M. Huber, and L. Oberhuemer. 2018. Leistbaren Wohnraum schaffen - Stadt weiter bauen. Potenziale der Nachverdichtung in einer wachsenden Stadt: Herausforderungen und Bausteine einer sozialverträglichen Umsetzung. Wien:

Hoffmann, M. and T. Krause. 2011. *Zahlentafeln für den Baubetrieb*. 8., überarb. und aktualis. Aufl.. ed, *Praxis*. Wiesbaden: Wiesbaden : Vieweg + Teubner.

Meyer-Bohe, W. 2008. *Baukonstruktion: ein Kompendium*. Stuttgart: Verlag W. Kohlhammer.

Kleemann, F., J. Lederer, H. Rechberger, and J. Fellner. 2017. GIS-based Analysis of Vienna's Material Stock in Buildings. Journal of Industrial Ecology 21(2): 368-380.

Lederer, J., A. Gassner, F. Keringer, U. Mollay, C. Schremmer, and J. Fellner. 2020. Material Flows and Stocks in the Urban Building Sector: A Case Study from Vienna for the Years 1990–2015. Sustainability 12(1): 300.

MA41. 2020a. Mesh of the building model of Vienna. http://www.wien.gv.at/stadtentwicklung/stadtvermessung/geodaten/bkm/index.html. Accessed 13.04.2020.

MA41. 2020b. Stadtplan Wien (City map Vienna). https://www.wien.gv.at/Stadtplan/. Accessed 13.04.2020.

Lederer, J., A. Gassner, F. Fellner, U. Mollay, and C. Schremmer. Submitted. Raw materials consumption and CDW generation of the urban building sector 2016-2050: a scenario-based material flow and stock analysis of Vienna. Submitted to the Journal of Cleaner Production.