MASS FLOW, ENERGY FLOW AND COSTS OF THE GERMAN BUILDING STOCK

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ABSTRACT

On behalf of a committee of the German parliament, a study of the mass, energy and monetary flows of the German building stock has been initiated. The approach was macro-economic (top-down) for the calculation of the overall flows and process oriented (bottom-up) for the detailed flows created by new construction, refurbishment, demolition and utilisation of buildings. The building stock has been modelled with a stochastic replacement model for a reference population of 160 buildings which are decomposed into elements, specifications and building materials. Specific data sets were used for the upstream and downstream parts. A scenario for the development of the building stock and the induced mass, energy and monetary flows was established.

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1 INTRODUCTION: OBJECTIVES, METHODE AND SYSTEM LIMITS

The committee for the protection of people and environment of the German parliament has initiated a study about mass, energy and monetary flow of the building sector. The objective was to assess the available information, to quantify the present flows, to estimate the development until 2030 and to identify needs for more detailed research. The described study [EQT96] has used a triple approach :

- estimation of the present flows (inventory) through a top-down and a bottom-up approach. The top-down approach uses general macro-economic and statistic data. The bottom-up approach is based on the decomposition of the building stock into buildings, parts, materials, etc. which are linked to a detailed process analysis. It is possible to determine an upper limit of the flows (top-down) and to understand the origin of the flows (bottom-up).
- estimation of the future development of the flows on basis of a dynamic model of the building stock. Because of the long life span of a building and its parts, a comparison of the present input and output does not allow to predict future behaviour of input and output.
- Through a systematic mapping of raw materials (process chains), building parts and auxiliary materials, it was possible to evaluate the environmental impact along the usual LCA methods [SET93] and CML criteria [HEI92], [ECO95] as well as the detailed toxicological effect of particular emissions and the dissipation of problematic materials through deposit and recycling.

The study is concerned with the building sector (housing and non-housing). The infrastructure constructions (transport, energy etc.) are outside the scope of the study. Energy consumption (heating, warm water and general electricity) during building

operation has been considered. The flows induced by use of buildings (production, food, furniture etc.) have not been considered.
It was necessary to find corresponding system limits for economic/statistic limits of the top-down and the physical limits of the bottom-up approach.

2 TOP - DOWN APPROACH

2.1 Mass flow

Top-down calculations are based on different production statistics and input-output matrix of the German economy. [STAB92],[STAB95]. The input/output matrix has 47 commodities in the final published form. It is possible to obtain more detailed information on demand. The detailed industrial production statistics of the German statistical office have 800 commodities. These data only take into consideration companies with more than 20 employees. According to [ATK94] 55% of employment in the construction sector is in enterprises with less than 20 employees. However the dominant material and component producers are large firms. The main problems encountered are the difficulties to distinguish inputs into the building sector from inputs into the infrastructure sector mainly for materials which are used in both sectors like sand, cement, bitumen etc.
From a methodological point of view the upstream system limits have to be clearly defined. There are large differences in the published data [BER95],[BAC96] according to the way bulk materials are handled (excavation and transfer of materials which do not enter the production of basic materials, excavation for buildings etc.). A special extension to the input output matrix which takes into account these flows (called „Rucksäcke“[1]) has been established [WUP95]. In the present study only direct inputs have been taken into account.
The output (building waste) can be estimated on the basis of two sources: general production statistics and local and regional surveys of building waste [LAG91]. System limits and surveying methods are very different. The industrial production statistics concentrates on production waste which are sold (or paid for) inside industry. Building waste surveys are based on surveys and local statistics. In addition the classification of building waste is often not respected or not clear. International comparisons are nearly impossible.

2.2 Energy flow

Embodied (final) energy can be estimated on basis of the energy supply from the energy sector and industrial energy demand through the input output matrix. It is possible to distinguish between embodied energy in products and embodied energy in services. Through process analysis [GEM95] [FRI95] it is possible to estimate the primary energy need and emissions caused by energy supply.
Use energy can also be determined through energy supply to the non industrial sector (households). It is however difficult to proceed to a more detailed allocation (e.g. residential and non residential heat). Primary energy and emissions can be determined in an analogous way.

2.3 Monetary flow

Statistical data for the annual building activity can be used to estimate the building investment costs. It takes into account only building operations subject to a building permit. The main consequence is that a considerable part of refurbishment and self construction is not taken into account. Furthermore, the prices indicated in the building permit application form are generally much lower than the real building costs. Costs for

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1 back-packs.

building operation are difficult to estimate because there are no specific statistical data available.
The emissions caused by industrial and other activities can be linked to the input-output matrix through a specific matrix of emitters. [ÖKP92]. There are different approaches to combine the input output techniques with hybrid and process analysis [HOH92].

3 BOTTOM - UP APPROACH

3.1 Composition of the building stock

The building stock which is the largest economic, physical and cultural capital of the industrialised countries, is not well known. The existing statistical data on building stock concern generally only housing and there is a focus on either economical (influence of housing subventions) or energetic (evolution of the demand, impact of different energy saving measures) issues. Most economic statistics are focused on new construction. As the statistical data are insufficient, most authors have adopted an approach, in which the building stock is represented by a small number of categories of „typical“ buildings [IKA95]. The advantage of that method is its simplicity, the disadvantage is that each typology represents a specific view and cannot be reused for other investigations. Above all it is impossible to establish the relations between different views (economic, ecological, energetic, constructive, social, etc.). For this reason another approach has been chosen: The whole stock is divided into use classes (12) and age classes (6) along the available statistical categories. For these age-use classes the number of buildings, the floor space and if available the volume is determined. Independently a large number of buildings is described in a very complete way decomposition a building into elements of a cost breakdown structure. The number of these reference (not „typical“) buildings will continue to grow. Each reference building is associated to a age-use class.

German building stock 1991		Age classes		Floor space [million m2]				
Use classes		<1870	-1918	-1948	-1965	-1978	-1990	Total
Housing	Detached fam.house	105,4	168,55	159,27	276,42	252,83	195,59	1158
	Terraced house	12,69	20,31	50	87,48	108,55	56	335
	Small Appart.B	74,58	119,32	124,93	260,91	194,75	115,7	890
	Large AppartB	16,89	27,02	12	47,27	92,57	45,36	241
	High Appart.B.				10,18	36,09	5,63	52
Non-housing	Offices	20,6	51,5	30,9	43,99	36,09	35,45	219
	Institutions	25,65	64,12	38,47	54,77	25,63	11,36	220
	Commerce-Shop	4,44	11,11	6,67	9,47	7,24	6,3	45
	Warehouses	61,47	153,68	92,21	131,02	100,1	87,31	626
	Factories	54,15	135,37	81,22	115,42	88,18	76,79	551
	Agricult.B	52,64	131,6	78,96	111,97	53,3	44,85	473
	Other	65,78	164,46	98,67	137,76	86,02	36,34	589

Table 1 : Floor space per age-use class of the German building stock in 1990

3.2 Building model

Buildings are dismantled along a cost breakdown structure into 6 element groups and about 50 elements. For each element (e.g. windows) there are specific instances like „window with wooden frame and double glazing with low emission coating“. These specific elements are described in turn by a set of building specifications comprising all the necessary materials and operations for the element at its definitive place in a building. Furthermore, there are refurbishment elements and demolition elements with their particular specifications. Elements and specifications can have specific properties (cost, thermal, acoustic, recycling, etc.). All material and process specifications are mapped to LCA inventories.

The mass flows are calculated for every dismantling level of the analysed building. Each element (and some specifications) have estimated life times. The replacement takes place in four ways :

- elements with life time < 10 years: current annual maintenance
- elements with life times > 10 and < 30 years: partial and total refurbishment
- elements with life times > 30 and < 60 years: total refurbishment
- elements with life time > 60 years: life time of the building.

For each age-use class the interval between refurbishments (average value) and the standard deviation has been estimated. If a building is not refurbished after a certain time it becomes vacant (vacancy distribution) and if it stays vacant a certain time, it is demolished(demolition distribution). This way of modelling describe the end of the life span more realistic than models working with fixed life times. Reality shows that there is no simple relation between the age of a building and its probability to be demolished; on the contrary, the older buildings are, the higher is the probability that they will survive (e.g. historical monuments). All buildings have been „aged“ in the described way from their original condition. For each building the mass flows are calculated for seven phases:

1. input new construction
2. output new construction
3. input partial refurbishment
4. output partial refurbishment
5. input total refurbishment
6. output total refurbishment
7. output demolition

This detailed calculation was done in order to be able to simulate the probable flows (input/output) for each material at a given future moment, which allows to simulate different recycling strategies.

The information of the cost elements is almost sufficient for a current annual heating energy need calculation along the CEN standard [EN92]. Cost elements contain the different layers of the hull of a building which allows to calculate the u-value. Transparent parts can be labelled with energy and light transmission values. Technical equipment (heaters, boilers, distribution systems, solar collectors etc.) can be labelled with efficiencies. The main extension to current cost element data is the orientation of transparent elements and the information which part of the hull is adjacent to soil and non heated zones. The general building occupation data has to be indicated (heated surface, number of persons, warm water needs, electricity needs etc.).

(Cost)-Elements are functional units for the designer, the contractor, the user and in case of demolition and recycling. The relevant information can be used through the whole life cycle of the building. In general there are two ways how cost per element can be composed of: on the basis of a post calculation of realised objects (synthetic market data) or on the basis of specifications with unit prices (analytic data). Specifications are the links to the contractor and to building realisation. From the point of view of time they do not change much, the only exception is their price. Most element catalogues are therefore based on such specifications allowing to compose a large number of different elements with a basic set of specifications. The refurbishment costs can be handled in an analogous way; in the form of „refurbishment-elements“ containing the disassembling, handling, cleaning and replacement operations. Use (e.g. cleaning) and current maintenance costs can also be attached to the same elements and priced.

The environmental impact is calculated by linking the specifications (or elements) to catalogues of building materials, construction processes [ÖIB95], energy and transport related processes. Building material catalogues are linked to larger databases [FRI95] [GEM95] allowing to calculate the emissions and the aggregated values. Most building components contain relatively small amounts (< 5% mass) of additional or auxiliary materials which can have undesired toxicological properties (even if their contribution to the global impact is modest because they appear in small quantities). Typical examples are solvents, concrete additives, pigments, herbicides, etc. The effects of these materials for workers, users and for the local environment can not be neglected. Furthermore there is a risk of accumulation of these materials through multiple recycling. On the basis of indications from a specialised Swiss study [BUW95] the definition of these auxiliary materials can be linked both to construction material catalogues and to specific work-protection prescription [GIS91].

4 COMPARISON OF TOP - DOWN AND BOTTOM - UP RESULTS IN THE REFERENCE YEAR

The calculated top-down mass flows are 3,6 t/P.y for input and 0,4 t/P.y for output. The input-output relation is 1:9. The corresponding bottom-up values are 1,8 t/P for input and 0,86 t/P for output (1:2). A detailed comparison shows that the main input differences occur from assumptions made about sand and gravel. It is difficult to verify the exact origin which can result from the partition building/infrastructure activities in the top-down approach and underestimation of foundations, parking space, surfacing and other constructions associated, but not part of individual buildings. The differences in output (which are inverse) probably occur from an underestimation of the flows in the surveys and the overestimation of output in the refurbishment model. There are practically no empirical studies about the output of refurbishment building sites. International comparisons show similar differences between top-down and bottom-up results.

The (final) energy flows for heating, warm water and building specific electricity consumption are rather well known through energy surveys. The bottom-up model shows a good correspondence with the values of other studies. The costs of building construction, refurbishment and maintenance-operation per age-use class correspond to the statistical estimation of the total building activity. The data are however not sufficiently reliable to answer questions concerning the refurbishment necessity and the long term consequences.

The flow of emissions is always calculated and can not be easily measured like energy and monetary flows. Therefore the results depend on system limits and general assumptions made on the basic data used. There have been no systematic comparisons between the different databases.

The links between some basic materials and auxiliary materials have been established. It is possible to estimate the probable mass flows, their cause and their dissipation. However it will be difficult to establish the correspondence with production statistics of these materials because the production data are not public for certain materials.

Specific mass flows in building stocks	Germany Top-down Prod. stat.		Bottom-up model		Switzerland Top-down Prod. stat.	[BUW95]	France Top-down Prod. stat.	[CSTB96]
Materials :	[t/P.y]	[%]	[t/P.y]	[%]	[t/P.y]	[%]	[t/P.y]	[%]
Sand-gravel	0,239	6,6	0,169	10,7		0,0		0,0
Brick	0,319	8,9	0,112	7,1	0,313	13,3	0,87	31,2
Si Bricks	0,154	4,3	0,11	7,0	0,066	2,8		0,0
Concrete	2,533	70,3	1,186	75,2	1,977	83,9	1,92	68,8
other	0,06	1,7						
not ident.	0,296	8,2						
Total mineral	**3,601**	**100,0**	**1,577**	**43,8**	**2,356**	**100,0**	**2,79**	**100,0**
Wood	0,136	41,3	0,1	52,6	0,086	36,9	0,081	45,5

Metals	0,095	28,9	0,031	16,3	0,08	34,3	0,087	48,9
Chem. Prod.	0,03	9,1	0,028	14,7	0,023	9,9		0,0
Ceramics	0,024	7,3	0,002	1,1		0,0		0,0
Plastic	0,023	7,0	0,022	11,6	0,028	12,0		0,0
Glass	0,006	1,8	0,007	3,7	0,016	6,9	0,01	5,6
other	0,015	4,6		0,0				
Total non mineral	**0,329**	**100,0**	**0,19**	**100,0**	**0,233**	**100,0**	**0,178**	**100,0**
Total input	**3,616**		**1,577**		**2,356**		**2,79**	

Input	Germany [EQK96] Top-down [t/P.y]	Germany [EQK96] Bottom-up [t/P.y]	Switzerland [WUE96] Bottom-up [t/P.y]	Germany [KRU94] Bottom-up [t/P.y]
New Construction		1,46	1,375	
Part. Refurbishment		0,15		
Tot. Refurbishment.		0,17		
Refurbishment.			0,375	
Total input	**3,61**	**1,78**	**1,75**	
Output :				
New Construction.		0,15		
Part. Refurbishment.		0,17		
Tot. Refurbishment.		0,21		
Refurbishment.			0,375	
Demolition		0,32	0,375	
Total output	**0,4**	**0,85**	**0,75**	**0,63**
Input/output	**9,03**	**2,09**	**2,33**	

Fig. 2 : Specific mass flows in the German building stock and international values

5 EVOLUTION OF THE BUILDING STOCK

The scenarios of evolution of the building stock are based on long term trends (demographic evolution and evolution of the buildings considered as population). For the non housing sector a conservative estimation of long term economic trends shows a declining tendency of needs in industry, service and public buildings. New construction has to be distinguished between replacement of demolished buildings and additional new construction. The new construction rate both in housing and non housing is estimated to approach 0,5% of the building stock in the long term.

Refurbishment activities are difficult to define. The interpretation of actual „trends" is problematic. The model indicates a „theoretically necessary" rate of refurbishment to ensure the long term durability of the stock. This value could be considered as an upper limit. Empirical studies on the state of degradation of the building stock show that the necessary rate of refurbishment is not attained for the moment and that there is a long term risk of gradual decrease of quality.

The rate of demolition is very low (<0,25%). Without the possibility to reconstruct a more profitable building at the same place, demolition is not attractive for building owners. The demolition probability is estimated to increase when a building is not refurbished in time and becomes vacant.

6 SIMULATION OF THE EVOLUTION: SCENARIO UNTIL 2020

The development of mass flows has been estimated on the basis of the bottom-up data (which mark the lower bound). They show an increase of the building stock until 2010 and then a slight decrease. The continious increase of the refurbishment part changes the input-output relation. On the basis of the actual knowledge, it is difficult to estimate if and when there is an equilibrium of input-output and if the offer of building waste for recycling (output) can correspond to the demand of (recycled) input materials.

The final energy demand is decreasing through the actually enforced energy savings measures. The reduction of approx. 20% until 2020 could be much larger through a more efficient energy policy and appropriate measures in exploitation, refurbishment and new building standards [IWU90].

The cost estimates show a decreasing volume of construction activities. As the predominant refurbishment part is much more labour intensive than new construction, the decrease of the construction activity could result in an increase of labour force. This would be consistent with the principle of „work instead of resources“.

The macro-economic consequences of the real refurbishment needs are difficult to estimate. Some authors estimate that refurbishment needs (and costs) will raise dramatically in the future. With reduction of new construction activities, most environmental indicators stay constant or regress. The only notable exemption is „special waste“. Other forms of impact (micro-climatic changes, sealing of the ground) or resource consumption (e.g. land use) should be analysed more in detail.

7 DISCUSSION OF THE RESULTS

This first study of the mass, energy and monetary flows of the national building stock has shown the need for more detailed and reliable statistical data of building stock, the building production, building material production and construction waste. Infrastructure activities have to be integrated in the same methodological and statistic framework. The parallel top-down and bottom-up approach has to be continued until a better correspondence between the results is achieved. The questions concerning the quantitative and qualitative development of the output/input relation have to be analysed soon in order to orient research and development towards the necessary techniques for transformation, reuse and recycling. [HAS95]. If the needs are known sufficiently in advance there is a large chance that the appropriated techniques will be ready in time.

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