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SPATIAL DIFFUSION OF ENERGY EFFICIENT BUILDINGS: A WESTERN EUROPEAN CASE STUDY

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Abstract: Among the various environmental problems arising today, special attention must be paid to the issues related to energy; in particular one of the most important tasks to address environmental issues is the decreasing of the energy consumption of buildings. As a result, much attention has been given recently to research projects aiming to analyze the technological, economical and environmental features of energy efficient buildings.
The goal of our paper is to examine the spatial diffusion of energy efficient buildings built in Germany which country plays a very important role in this field. Within the framework of our research we will highlights the differences between the German "Länder" (federal states) and the settlements of different sizes, as well as, the observable peculiarities with regard to the individual building types.

Key words: energy efficient buildings, sizes of settlements, Germany, functions of buildings

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INTRODUCTION

In our days, energy issues belong to the most important problems facing the Earth, the solution of which may be expected partly from decreasing the amount of the energy used and partly from the increased utilisation of renewable energy resources. In the light of this, it is not surprising that the European Union in its Europe2020 Strategy (European Commission, 2010) drafted rather ambitious concepts in these two areas: by 2020 the European Commission considers it necessary to increase the share of renewable energy sources in the final energy consumption to 20%, and to reach a 20% increase in energy efficiency. A substantial part of energy consumption is related to buildings and includes, inter alia, the use for cooling/heating, lighting, and cooking purposes.

In the view of the above, since the late 1980s, special attention has been paid to minimising the energy consumption of buildings and the idea of energy efficient building (in more popular term: passive houses) was born within the framework of this. The a passive

house is a building for which thermal comfort can be achieved solely by postheating or postcooling of the fresh air mass without a need for recirculated air (Mlecnik – Marrecau, 2008).

The international literature dealing with passive houses so far analysed mainly the technological and financial conditions, and included, inter alia, research concentrating on the operation (Badescu, 2007a; Feist et al., 2005; Wall, 2006), economy (Audenaert et al., 2008; Badescu, 2007b; Chel – Tiwari, 2009; Dodoo et al., 2010; Kozma, 2008) and environmental aspects (Mahdavi – Doppelbaue, 2010; Thiers – Peuportier, 2008) of passive houses.

In recent years, however, only very little attention has been paid to the number and geographic range of the passive houses in the course of the researches – which may be mostly explained by the lack or absence of information and the uncertainties in the data concerning the number of passive houses built in the World.

Publications in this category (Kozma et al., 2014; Lang, 2010) indicated that that Germany is one of the most important areas where passive houses are widespread, for which reason we consider a more detailed examination of this country necessary. In the course of this, on the one hand, we will discuss the place of Germany within the world, and on the other hand, we will examine the situation within the country. The aim of the paper is to study the changes in the construction of passive houses over time; in addition, the differences between German "Länder" (federal states), as well as the observable peculiarities with regard to the individual building types are also presented.

MATERIALS AND METHODS

The study relied partly on the database of the Passive House Institute, and partly on the database of the International Passive House Association, which have provided the most important information by years, countries and regions (for example, the geographic location, size or function of a given building). The source of the data concerning the population and the income situation of the individual federal states was the German Statistical Office. All the obtained results were statistically evaluated by the method of descriptive statistics (%). The data was statistically analyzed using the Statistical Package for Social Sciences (SPSS)/14.0.

RESULTS AND DISCUSSION

In recent decades, the number of passive houses and their size increased worldwide: while only 268 such buildings were reported in 2000 (their size was 103,960 m^2), by 2012, this number has approached 3,000 (their size was 1,623,870 m^2). The analysis of the data from Germany reveals an outstanding role played by the country: regarding the total number of passive houses: in 2012 their share in the total stock of buildings was 59,5%, while in terms of ground area it is 45,3%. This very high percentage is fundamentally due to the fact that the idea of the passive house itself was born in Germany, and a natural consequence of this was that such buildings first appeared in Germany. At the same time, examining the changes over time, a decreasing significance of the country can also be observed: while in 2000, the country's share in the total stock of buildings was 80.2%, by 2012 this decreased to 59,5%. In the background of this decreased was primarily the success of such buildings, as well as the fact that increasing efficiency and decreasing price of the technology used was also very attractive to builders in other countries, as a result of which significant investments were made in this area.

If we examine the situation within Germany (Table 1), the outstanding role of two federal states (Baden-Württemberg and Bavaria) can be highlighted (nearly 50% of all passive houses are built here); the second large group consists of North Rhine-Westphalia, Hesse, Rhineland-Palatinate, and Lower Saxony, while the share of the other federal states combined is less than 5%. Concerning the changes over time, several market processes can be observed (due to the low number of elements, no convincing conclusions can be drawn yet on the basis of the figures from 1997/98):
- As a general tendency, the federal states other than the six outstanding ones have gradually increased their shares over time: their combined share in 1999/2000 was only 9.4%, which increased to 17.9% by 2011/2012. There are fundamentally two factors behind this process. On the one hand, the first passive house was built in Darmstadt in the state of Hesse in 1991, and in the initial period passive houses mainly spread in the areas neighbouring with this state. On the other hand, the technology became less expensive over time, and as a consequence, its application became more cost-efficient in states with lower income levels.
- The two federal states in the top positions went opposite ways: in case of Baden-Württemberg there was a significant setback, while Bavaria forged ahead.
- In addition to Bavaria, the increase was particularly significant in the federal states of Saxony and Hamburg.

Table 1 Changes in the distribution of passive houses in Germany federal states between 1997 and 2012 (%)

	A	B	C	D	E	F	G	H	Σ
Baden-Württemberg	31.8	39.3	23.6	27.2	21.6	15.9	18.8	15.9	22.2
Bavaria	15.8	18.7	25.3	24.2	23.5	24.2	30.6	32.6	26.1
Berlin	0.0	0.0	0.6	0.0	0.7	0.3	1.2	1.0	0.6
Brandenburg	0.0	2.4	2.8	1.9	1.8	0.7	3.0	2.0	2.0
Bremen	0.0	0.0	1.1	0.0	0.0	1.0	0.3	0.0	0.3
Hamburg	2.3	0.0	1.7	1.6	1.5	2.1	2.7	4.7	2.2
Hesse	18.2	12.4	9.0	8.6	9.9	10.7	6.5	10.2	9.6
Mecklenburg-Vorpommern	0.0	0.6	0.0	0.4	0.4	0.3	0.6	0.0	0.3
Lower Saxony	15.9	5.9	6.2	5.4	8.8	10.0	7.1	6.8	7.5
North Rhine-Westphalia	11.4	6.5	11.2	11.3	17.2	14.5	12.5	12.2	12.6
Rhineland-Palatinate	2.3	7.6	10.1	10.1	6.2	10.7	8.0	5.1	8.0
Saarland	0.0	0.6	0.0	0.4	0.4	0.3	0.6	0.3	0.4
Saxony	2.3	1.2	1.7	2.3	3.3	5.5	3.9	5.8	3.6
Saxony-Anhalt	0.0	1.8	0.6	0.4	0.0	0.0	0.6	0.0	0.4
Schleswig-Holstein	0.0	1.8	3.9	5.8	2.9	2.4	2.1	2.7	3.0
Thuringia	0.0	1.2	2.2	0.4	1.8	1.4	1.5	0.7	1.2

A – 1997/1998, B- 1999/2000, C – 2001/2002, D – 2003/2004, E – 2005/2006, F – 2007/2008, G – 2009/2010, H – 2011/2012
Source: databases of the Passive House Institute and the International Passive House Association

At the same time, the actual processes are better reflected by the relative data (also taking into consideration population size) pertaining to passive houses (Table 2). If we consider the top six states, there are only two new states that enter the picture relative to the proportion expressed by the percentage: Hamburg and Schleswig-Holstein. The analysis of the reasons behind why passive houses are widespread, an important factor is the income level of the population, which can be explained by the fact that the construction of these buildings involves significant additional costs.

According to the available data, the top give states in the ranking according to 100,000 population are also the top 5 states in terms of income. If we examine the opposite extreme, i.e. the end of the ranking, the situation is not so clear. From the point of view of

how widespread passive houses are, only two of the five states (Mecklenburg-Vorpommern and Saxony-Anhalt) at the bottom of the list are among those that also have the lowest income figures. The strong link between the two factors is shown by the very high value of the correlation coefficient, +0.787, which suggests a significant connection.

Table 2 The relative data of passive houses and the income situation of the population in the different federal states of Germany

	A	B
Bavaria	3.87	109.8
Baden-Württemberg	3.84	108.3
Rhineland-Palatinate	3.67	102.5
Hesse	2.92	103.5
Hamburg	2.35	109.3
Schleswig-Holstein	1.96	100.9
Lower Saxony	1.75	95.1
Saxony	1.55	86.7
Brandenburg	1.45	86.9
North Rhine-Westphalia	1.29	101.2
Thuringia	0.97	84.4
Bremen	0.90	100.3
Saarland	0.66	94.2
Mecklenburg-Vorpommern	0.35	82.1
Berlin	0.32	90.1
Saxony-Anhalt	0.28	82.5

A – the number of passive houses per 100,000 population, B – the income situation of the individual states (the average of income per capita between 1997 and 2011 relative to the German figure – 100.0%)
Source: databases of the Passive House Institute and the International Passive House Association

Passive houses may have different functions, and examining Germany from this point of view reveals that there are differences from the general tendencies around the world in two areas (Table 3). Firstly, the proportion of residential-purpose passive houses is higher in Germany (this is particularly true in case of other residential functions), and secondly, the proportion of commercial-purpose passive houses (e.g. commercial office buildings, industrial halls, hotels) is significantly lower.

Table 3 Functions of the passive houses in the World and Germany

	World	Germany
detached single family house	60.6	57.9
other residential function*	26.8	31.3
residential function in total	87.4	89.2
administrative function	3.7	3.8
mixed (residential and market) function	1.4	1.5
market function (commercial purpose passive houses)	1.9	0.6
education function	4.2	3.5
sport function	0.7	0.8
social and healthcare function	0.8	0.7
total	100.0	100.0

Source: databases of the Passive House Institute and the International Passive House Association

Analysing the changes of the functions in time (Table 4), however, a very substantial shift of emphasis may be observed. More than 90% of the buildings constructed during the early years (second half of the 1990s) belonged to the category of residential function, and the significance of the other functions gradually increased after the millennium. This essentially may be explained by the fact that as a result of the improvement of the technology and the increase in the number of positive experiences, the applied method became popular among the other actors as well (mostly from the public sector). The decrease of the residential function was particularly salient after 2007, which is due to the fact that the income of the population decreased as a result of the crisis, which also decreased activities of this type, while the public and the market sector still considered these investments important.

Table 4 Changes in the functions of passive houses in time in Germany between 1997 and 2012 (%)

	A	B	C	D	E	F	G	H
detached single family house	53.3	55.4	61.8	62.1	61.9	54.2	58.6	52.5
other residential function*	42.2	38.6	33.2	30.1	31.8	31.1	27.0	29.4
residential function in total	95.5	94.0	95.0	92.2	93.7	85.3	85.6	81.9
administrative function	4.5	3.6	2.2	1.6	1.8	7.2	3.0	6.5
mixed (residential and market) function	0.0	0.0	1.1	2.3	2.2	1.4	1.8	1.0
market function (commercial purpose passive houses)	0.0	0.6	0.0	0.0	0.4	0.7	1.2	0.3
education function	0.0	1.8	1.7	2.7	1.1	3.4	5.7	8.2
sport function	0.0	0.0	0.0	0.4	0.4	1.0	2.1	0.7
social and healthcare function	0.0	0.0	0.0	0.8	0.4	1.0	0.6	1.4
total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

A – 1997/1998, B- 1999/2000, C – 2001/2002, D – 2003/2004, E – 2005/2006, F – 2007/2008, G – 2009/2010, H – 2011/2012
Source: databases of the Passive House Institute and the International Passive House Association

An examination of the distribution of passive houses of different functions across the federal states leads to several findings (Table 5). Firstly, in a large number of the states, the residential function accounts for more than 80%, with lower values only observed in case of Brandenburg and Saxony. This is fundamentally due to the fact that the above two states are overrepresented as far as passive houses built after 2008 are concerned, and in these years – as mentioned before – uses other than for residential purpose were of increasing importance.

Secondly, within the residential function, the dominance of detached houses is general, from which only the federal states of Hamburg and Hesse are exceptions. The first is fundamentally due to the fact that the free space for the construction of detached houses is limited in Hamburg, and therefore, other residential functions (e.g. rows of houses, condominium buildings) dominate. In the case of Hesse, the most important factor is that a larger-than-average proportion of residential-purpose buildings can be found in the five largest settlements (this number in this federal state is 24.2 while the average number of

Germany is 17.1%), where it is primarily buildings other than detached houses that are constructed due to the lack of space.

Thirdly, as far as non-residential functions are concerned, it is only in a few cases that overrepresentation of a higher extent can be observed: in Brandenburg it is sports, education and mixed functions, in Hesse it is education, in North Rhine-Westphalia the social and healthcare, in Saxony the administrative, education and sport, in Schleswig-Holstein the market, while in Thuringia it is the market, social and healthcare functions that significantly exceed the national average.

Table 5 The distribution of passive houses completed in the German federal states between 1997 and 2012 (only states with at least 20 passive houses are included)

	A	B	C	D	E	F	G	H	I
Baden-Württemberg	54.2	36.5	90.7	3.4	1.7	0.2	3.2	0.5	0.2
Bavaria	62.8	26.8	89.6	3.3	1.9	1.3	3.5	0.4	0.0
Brandenburg	59.5	18.9	78.4	2.7	5.4	0.0	8.1	5.4	0.0
Hamburg	34.2	58.6	92.8	2.4	2.4	0.0	2.4	0.0	0.0
Hesse	41.2	42.9	84.1	5.1	0.6	0.6	7.3	1.7	0.6
Lower Saxony	69.8	18.8	88.6	4.3	0.7	0.0	5.0	0.7	0.7
North Rhine-Westphalia	57.4	32.4	89.8	4.3	0.4	0.0	1.7	0.4	3.4
Rhineland-Palatinate	64.1	27.7	91.8	4.1	2.0	0.0	1.4	0.7	0.0
Saxony	52.2	23.9	76.1	7.5	1.5	1.5	10.4	3.0	0.0
Schleswig-Holstein	54.5	32.8	87.3	5.5	0.0	3.6	0.0	1.8	1.8
Thuringia	69.6	17.5	87.1	0.0	0.0	4.3	4.3	0.0	4.3
Germany	57.9	31.3	89.2	3.8	1.5	0.6	3.5	0.8	0.7

A – detached single family house, B – other residential function, C – residential function in total, D – administrative function, E – mixed (residential and market) function, F – market function (commercial purpose passive houses), G – education function, H – sport function, I – social and healthcare function
Source: databases of the Passive House Institute and the International Passive House Association

Earlier it has already been mentioned that passive houses of different functions were built on settlements of different sizes. The detailed analysis of the data (Table 6) sheds light on several important facts. One the one had, we can observe that in the majority of the federal states, in case of larger settlements, relative to the share of passive houses, the proportion of residential buildings is lower while the proportion of buildings of other functions is higher. In the background of this lies the fact that settlements of larger population generally also play some central role and the buildings for such purposes are generally concentrated in these settlements, and so in the spirit of energy savings, the passive house technology is used in case of some of them. Further, the local governments and companies of larger settlements generally have bigger financial resources, and thus they are able to finance the higher investment costs.

Another important fact is that the proportion of detached single family passive houses is lower, while the proportion of buildings with other residential function (e.g. condominium buildings, rows of houses, apartment buildings) is higher than the average in case of larger settlements. This is fundamentally due to the fact that on smaller settlements, due to the available space, detached single family houses are built much more frequently, while on larger settlements, due to the constraints of space, buildings of other residential function are more important.

Table 6 The distribution of buildings of various functions on the basis of the population size of the settlements concerned (in %, with only those states included in the table that have 20 passive houses in both settlement categories; data for Germany aggregated from the data for the states; the table does not include the data for the three cities of state status, i.e. Berlin, Bremen and Hamburg)

		single family house	other residential function	residential function in total	other function	total
Baden-Württemberg	1	26.3	63.2	89.5	10.5	100.0
	2	58.7	32.2	90.9	9.1	100.0
Bavaria	1	37.9	45.9	83.8	16.2	100.0
	2	64.9	25.1	90.0	10.0	100.0
Hesse	1	10.0	62.0	72.0	28.0	100.0
	2	53.5	35.6	89.0	11.0	100.0
Lower Saxony	1	60.5	26.3	86.8	13.2	100.0
	2	73.3	15.8	89.1	10.9	100.0
North Rhine-Westphalia	1	51.9	37.0	88.9	11.1	100.0
	2	58.1	31.7	89.8	10.2	100.0
Rhineland-Palatinate	1	48.5	48.5	97.0	3.0	100.0
	2	68.7	21.7	90.4	9.6	100.0
Saxony	1	51.4	28.6	80.0	20.0	100.0
	2	53.1	18.8	71.9	28.1	100.0
Germany	1	39.7	44.7	84.4	15.6	100.0
	2	62.2	27.4	89.6	10.4	100.0

1- the five largest cities of the given federal state, 2 - the settlements other than the five largest cities of the given federal state
Source: databases of the Passive House Institute and the International Passive House Association

The passive houses with different functions, of course, differ in their ground base (Figure 3). The largest ground areas belong to social and healthcare facilities, followed by educational buildings, while in case of administrative, sports-related and mixed use the ground areas are more or less the same. In case of the residential function, the average ground area is below 500 square metres, and is of course much smaller in case of detached single family houses than buildings incorporating several units.

The relationship between the ground area of the passive houses and the German federal states is primarily worth examining from the point of view of the number of passive houses (Table 7). The analysis of the data reveals that in several cases there are significant differences between the number of passive houses and their ground area relative to the total stock of buildings. The high number of passive houses relative to ground area is characteristic mainly in Bavaria, Lower Saxony and Thuringia, which can be explained by the fact that the proportion of the detached single family passive houses with the smallest ground area is the highest in these states. The opposite extreme (where the relative proportion of the ground area of the passive houses to the total for the country significantly exceeds the relative proportion of the number of passive houses) are represented by Brandenburg, Hamburg and Hesse: in the latter two states, the higher-than-average role of other residential functions is characteristic (Table 5), which is supplemented in the case of Hesse by a high share of the education function, which can be characterized by significant average ground areas. In the

case of Brandenburg, the outstanding role of other functions associated with larger average ground areas can be observed (Table 5), within which – similarly to Hesse – the educational function fulfils an important role.

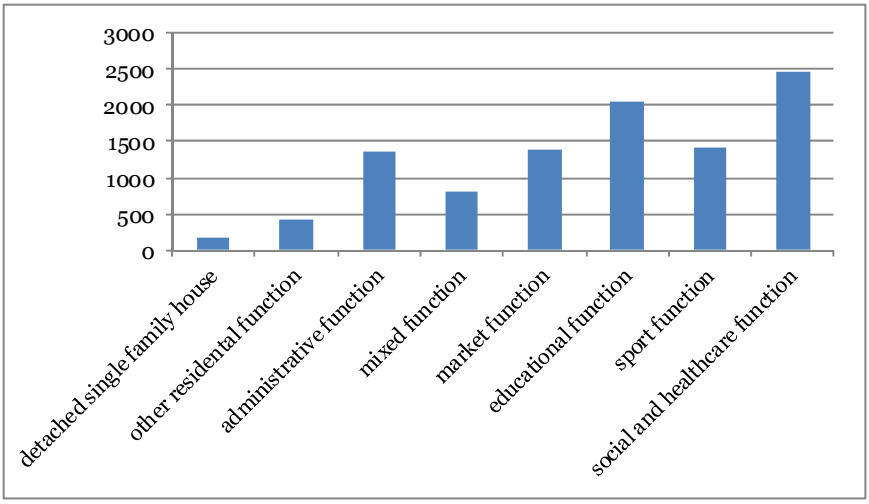

Figure 1 Average ground area of the passive houses built in Germany between 1997 and 2012 with different functions (m²)

Source: databases of the Passive House Institute and the International Passive House Association

Table 7 Distribution of ground area and number of passive houses by federal states of Germany (%)

	ground area of passive houses	number of passive houses
Baden-Württemberg	21.1	21.7
Bavaria	20.3	26.4
Berlin	1.0	0.6
Brandenburg	3.3	1.9
Bremen	0.3	0.3
Hamburg	3.6	2.3
Hesse	18.7	9.5
Mecklenburg-Vorpommern	0.1	0.3
Lower Saxony	5.7	7.5
North Rhine-Westphalia	11.2	12.7
Rhineland-Palatinate	6.5	8.0
Saarland	0.1	0.4
Saxony	4.7	3.7
Saxony-Anhalt	0.1	0.4
Schleswig-Holstein	2.6	3.0
Thuringia	0.7	1.3
total	100.0	100.0

Source: databases of the Passive House Institute and the International Passive House Association

Earlier it was mentioned that detached single family houses account for a significant share within the stock of passive houses, and therefore, a more detailed examination of these could contribute to the drawing of some useful conclusions. The data call attention to the importance of income conditions (Table 8): in the order according to the average ground area of detached single family houses, from the five states at the top four are also in the top five according to income, and the same tendency can also be observed in case of the five states at the bottom of the list.

Table 8 The average ground area of detached single family passive houses and the income situation in the given federal state (only states with at least 20 detached houses are included in the table)

	A	B
Rhineland-Palatinate	194.6	102.5
Bavaria	194.0	109.8
Hesse	191.4	103.5
Baden-Württemberg	185.9	108.3
Hamburg	180.1	109.3
Saxony	178.0	86.7
Lower Saxony	177.0	95.1
North Rhine-Westphalia	176.0	101.2
Brandenburg	172.6	86.9
Thuringia	168.4	84.4
Schleswig-Holstein	154.0	100.9

A – the average ground area of detached houses (m^2), B – the income situation in the states (with the average amount of per capita income in Germany between 1997 and 2011 being 100.0%)
Source: databases of the Passive House Institute and the International Passive House Association

CONCLUSIONS

The most important conclusions can be summarised as follows: In accordance with the international trends, the increase in the number of passive houses in Germany also accelerated in the first decade of the 21st century; however, as a result of the economic crisis, the rate of increase slowed down and at the same time the proportion of Germany's share from the stock of passive houses worldwide gradually decreased. An examination of the distribution of passive houses within Germany reveals that the initial geographical concentration gradually decreased with time, and that the significance of passive houses in each of the federal states is significantly influenced by the income situation in the given state. Considering the functions of the passive houses, in the first years the residential function was predominant; however, the significance of other – especially educational – functions gradually increased in the past few years. Within the residential function, the role of detached houses is of outstanding significance; different values can be primarily explained with the geographical characteristics of the given state. The size of a settlement plays an important role in determining the functions of passive houses there.

REFERENCES

Audenaert, A. – De Cleyn, S.H. – Vankerckhove, B. (2008) Economic analysis of passive houses and low-energy houses compared with standard houses. *Energy Policy*, 36(1), 47-55.

Badescu, V. (2007a) Simple and accurate model for the ground heat exchanger of a passive house. *Renewable Energy*, 32(5), 845-855.

Badescu, V. (2007b) Economic aspects of using ground thermal energy for passive house heating. *Renewable Energy*, 32(6), 895-903.

Chel, A. – Tiwari, G.N. (2009) Thermal performance and embodied energy analysis of a passive house – Case study of vault roof mud-house in India. *Applied Energy*, 86(10), 1956-1969.

Dodoo, A. – Gustavsson, L. – Sathre, R. (2010) Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard. Resources. *Conservation and Recycling*, 54(12), 1152-1160.

European Commission (2010) *Europe 2020: A European strategy for smart, sustainable and inclusive growth*. Brussels

Feist, W. – Schnieders, J. – Dorer, V. – Haas, A. (2005) Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept. *Energy and Buildings*, 37(11), 1186-1203.

Kozma, G. (2008) Characteristic Features of the Economic Management of Local Authorities in the Western and the Eastern Border Areas of Hungary. In (ed. I. Süli-Zakar) *Neighbours and Partners – On the two sides of the border*, Debrecen, 19-26.

Kozma, G. – Molnár, E. – Kulcsár, B. – Pénzes, J. – Teperics, K. – Radics, Zs. (2014) Characteristics of energy efficient buildings in different regions of Europe, *Environmental Engineering and Management Journal*, 13(11), 2831-2836

Lang, G. (2010) *Establishment of a Co-operation Network of Passive House Promoters* (PASS-NET), Ministry for Transport, Innovation and Technology, Wien

Mahdavi, A. – Doppelbauer, E. (2010) A performance comparison of passive and low-energy buildings. *Energy and Buildings*, 42(8), 1314-1319.

Mlecnik, E. – Marrecau, C. (2008) Passive house projects in Belgium. *International Journal of Environmental Technology and Management*, 9(4),390-401.

Thiers, S. – Peuportier, B. (2008) Thermal and environmental assessment of a passive building equipped with an earth-to-air heat exchanger in France. *Solar Energy*, 82(9), 820-831.

Wall, M. (2006) Energy-efficient terrace houses in Sweden: Simulations and measurements. *Energy and Buildings*, 38(6), 627-634.