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The prebound-effect in detail: real indoor temperatures in basements and measured versus calculated U-values

Caroline Hoffmann[a]*, Achim Geissler[a]

[a]*Intitut Energie am Bau, Fachhochschule Nordwestschweiz, St. Jakob-Strasse 84, 4132 Muttenz, Switzerland*

Abstract

This paper focuses on the topics U-values and indoor air temperatures of unheated basements with uninsulated cellar ceilings. Measurement values are compared with calculation procedures suggested by building regulations. Concerning the U-values it is shown that they are typically considered to be higher (i.e. worse) in uninsulated existing constructions than they effectively are. Measured temperatures in seven basements are higher (around 8 K) than a calculation according to regulations would yield. The paper derives suggestions for the adjustment of calculations focused on existing residential buildings.

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Keywords: U-value, measurement, calculation, basement temperature, domestic buildings, existing buildings, prebound-effect

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1. Introduction

The research project "Issues in regard to the suitability of SIA 380/1 as a tool to predict the energy demand in existing dwellings" [1],[2] tracked down possible prebound-effects in 33 buildings. It was found that there is no single,

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* Caroline Hoffmann. Tel.: +41 61 467 45 72; fax: +41 61 467 45 43.
E-mail address: caroline.hoffmann@fhnw.ch

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systematic fault in the underlying calculation procedure. It is demonstrated that there are a number of possible reasons for the deviations often found between calculated demand and measured consumption for space heating. Among these are too poor U-values used for calculations, too low indoor air temperatures assumed for unheated basements and discrepancies between actual local outside temperatures and ambient temperatures according to “official” climate data sets. In this paper, the focus lies on the topics U-values and indoor air temperatures of unheated basements. Measurement values are compared with calculation procedures suggested by building regulations and suggestions for the adjustment of calculations focused on existing buildings are derived.

Nomenclature

b	b-factor [-], adjustment factor for thermal transmittance
c	convection [index]
e	exterior [index]
H_{iu}	specific heat transfer coefficient for transmission between unconditioned and conditioned space [W/K]
H_{ue}	specific heat transfer coefficient for transmission between unconditioned and exterior [W/K]
h	surface heat transfer coefficient [$W/(m^2 K)$]
R	thermal resistance [$m^2 \cdot K/W$]
r	radiation [index]
rem	remainder [index]
se	external surface [index]
U	thermal transmittance [$W/(m^2 K)$]
θ_u	temperature in unconditioned space [°C]
σ	standard deviation, $\sigma = SQRT(1/(N-1)\sum_j(\bar{x}-x_j)^2)$

2. Methods

2.1. U-values

Nine different constructions of existing and mostly uninsulated buildings are selected (refer to Table 1). Each U-value is measured with a measurement device consisting of one heat flux sensor and two temperature sensors (gSKIN® U-value KIT, greenTEG [www.greenteg.ch]). The U-values of each of these constructions are independently calculated by 10 energy consultants (experts for Swiss cantons´ building energy label GEAK). The consultants were given detailed descriptions of the constructions, however needed to make their own assumptions in regard to thermal conductivity values of the materials involved. This closely represents the typical level of information for energy audits of buildings. The U-values are calculated according to SN EN ISO 6946:2007 [3], see equation (1), with a fixed R_{se} of 0.04 $m^2 \cdot K/W$.

Table 1: Measured and calculated constructions. Abbreviations used: pl. = plaster

Building	Year of building	Construction (from outside to inside)
Zürich 01	1905	pl., 30 cm brick, pl.
Münchenstein 01 (basement 1, B1)	1925	pl., 40 cm (hand) tamped concrete
Münchenstein 01 (ground floor, G)	1925	pl., 2*12 cm brick with 6 cm air gap, pl.
Rheinfelden 01	~1600	pl., 55 cm rubble masonry of sandstone, 3 cm air gap, 2.5 cm pl. board
Küttingen 01	1953	30 cm reinforced concrete
Wegenstetten 01	1850	pl., 67.5 cm limestone, 3 cm wood cladding
Muhen 01	1965	pl., 2*12 cm honeycomb brick with 3 cm core insulation (glass wool)
Reinach 01 (insulated concrete, IC)	1962/63	pl., 6 cm insulation (mineral wool), 30 cm concrete, pl.
Reinach 01 (uninsulated special concrete, USC)	1962/63	pl., 30 cm special concrete, pl.

$$U = \frac{1}{\sum R} = \frac{1}{R_{se} + \sum R_{rem}} = \frac{1}{\frac{1}{h_{c,e} + h_{r,e}} + \sum R_{rem}} \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}\right] \tag{1}$$

2.2. Temperatures of basements with uninsulated cellar ceiling

In six unheated basements (see Table 2), temperature measurements were conducted during the winter of 2015/16. In one basement, values were acquired during the winters of 2012 through 2015. In all of the basements neither the ceiling nor the walls were insulated. The rooms were not conditioned. However, some air exchange may have occurred.

Table 2: Buildings in which basement temperatures are measured.

Building	Year of building	Building type	Boundary conditions of basement walls
Zürich (Office)	1951	Office	ground
Basel 07	1928	single family house	2/3 ground, 1/3 air
Basel 08	~1950	multi-family house	ground
Basel 09	~1950	multi-family house	2/3 ground, 1/3 air
Basel 10	1918	multi-family house	2/3 ground, 1/3 air
Münchenstein 01	1925	single family house	2/3 ground, 1/3 air
Reinach 01	1962/63	multi-family house	2/3 ground, 1/3 air

In Swiss and German building regulations (e.g. SIA 380/1:2016, DIN V 4108-6:2003-06 or DIN 18599-10:2011-12) the conditions and the component properties of (unheated) basements are taken into account in the calculations by so called ‘adjustment factors’ for thermal transmittance, the b-factor or fx-factor. For an exemplary basement, the temperatures and the corresponding b-factor (for the ceiling) are calculated according to SN EN ISO 13789 (see equations (2) and (3)). The following boundary conditions apply for the calculation: The basement floor is 2 m below ground level and is uninsulated. Construction U-values are: wall facing exterior 0.9 W/(m^2 K), wall facing ground 0.5 W/(m^2 K) and basement floor 1.0 W/(m^2 K)). The U-values for the components adjoining ground are adjusted by the appropriate b-factors. The ground floor above the basement is conditioned (walls: 0.55 W/(m^2 K), floor 0.8 W/(m^2 K)). To represent the outdoor conditions, the temperatures of the measuring period are used (weakly mean).

$$b = \frac{H_{ue}}{H_{iu} + H_{ue}} \tag{2}$$

$$\theta_u = \frac{\theta_i H_{iu} + \theta_e H_{ue}}{H_{iu} + H_{ue}} \tag{3}$$

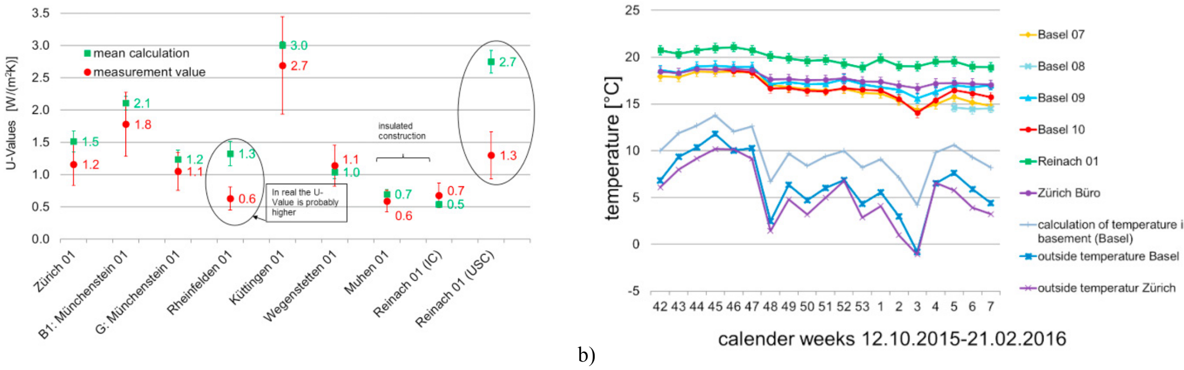
3. Measurement and calculation results

3.1. U-values

For seven constructions, the calculated U-values are found to be higher than the measured ones (Fig. 1 (a)). The deviation of the measured values compared with average values of the calculations are between 12 and 111%. However, on a 95%-level, the discrepancy between measured and mean values of the calculation is found to be significant for two constructions, only. However, the result in Rheinfelden 01 is questionable, since there is an air gap behind the plasterboard and therefore no thermal coupling to the wall itself. The measurement does not take this into account.

3.2. Temperatures of basements with uninsulated cellar ceiling

The basement temperatures are found to be between a minimum of 13 °C and a maximum of 21 °C (Fig. 1 (b)). The outdoor temperatures during these periods were between -0.8 and 13.8 °C on a weekly average. Overall, the measurement results are between 2.3 and 5 K apart from each other. Omitting one building with exceptionally high temperatures (Reinach 01) the difference would be 0.5 to 2.5 K. Summarising all measurements, the minimal basement temperature is 13 °C. Basement temperatures calculated according to EN ISO 13789 are found to be significantly lower, namely on average by 7.3 K (omitting Reinach 01 and 2 σ = 3 K).



a) b)

Fig. 1 (a): Measured and calculated U-values of nine constructions from existing buildings. Calculated and measured values are shown with 2 σ error bars. The measurement uncertainty according to the manufacturer is assumed to be 1 σ; definite information on this was unavailable. The measurements were done between January - February 2016. Each measurement period had a minimum of 72 hours. All measurements were done with the U-value-KIT gSKIN from GreenTEG. Measurement uncertainty: 14% (according to GreenTEG), from the author´s point of view it may even be higher. The calculations were done by 10 energy consultants. They were provided with specifications of the construction (photos of the situation, plans and information on the layer structure). Thermal conductivity of the materials and the measurement results were not provided. The standard deviation of the values reported by the energy consultants was found to be between 0.04 (Reinach 01 (IC) and 0.34 (Reinach 01 (USC).
(b): Measured indoor air temperatures in basements from 12th of October 2015 until 21st of February 2016. Measurement device: Testo Logger 175-H2. Measurement cycle: every 60 minutes. Accuracy: ±0.5°C (manufacturer). The measurements were done in six existing buildings with uninsulated cellar ceilings. The building Reinach 01 has a boiler room in the basement, which emits a considerable amount of heat to the adjacent rooms, one of which was the measured room. The calculation of the indoor temperature in the basement is done for a typical fully underground cellar (PR_01) according to SN EN ISO 13789 [4]

4. Discussion

4.1. U-values

From the comparison of measurements and calculations it is concluded that U values are often considered to be higher (i.e. worse) in uninsulated existing constructions than they effectively are. One reason for the deviations can be found in the external heat transfer coefficient (see Table 3) used to calculate the U-value. Simulations [5] which calculate the heat transfer coefficient for different wind velocities and angles of inflow show that the normative heat transfer coefficients in the building regulations (e.g. EN ISO 6946) are very "conservative" (+42% higher). The standard R_{se} of 0.04 $m^2{\cdot}K/W$ is based on the assumption of 4 m/s wind velocity. For comparison: the average wind velocity during the heating period (15.10.-15.04.) for the DRY Zurich is below 3 m/s during 71% of the time.

Table 3. Overview of normative and measured or simulated heat transfer coefficients, h. Used abbreviations: h_i = h inside, h_a = h outside, v = wind velocity, h_c = heat transfer by convection, h_r = heat transfer by radiation

	Reference [-]	hi [W/m²K]	H_e [W/m²K]	V [m/s]
SN EN ISO 6946:2007 ($h_c + h_r$)	[3]	7.7	25	4
SN EN ISO 6946:2007 ($h_c + h_r$)	[3]	7.7	12.5	1
SN EN ISO 6946:2007 ($h_c + h_r$)	[3]	7.7	9.0	0
measurement 6 constructions (probably $h_c + h_r$)	[6]	5.6	4.0	diverse
Simulation: angle of incidence façade 0 to 90° (probably h_c)	[5]	-	15.0-17.5	4

U-values as a base for energy calculations in the design phase deliberately had a safety margin. This was desired by the authorities to enforce thermally improved constructions. The comparatively high external heat transfer coefficient gave such a safety margin when U-values > 0.8 W/(m^2 K) are considered. However, if the energy demand of an existing building is to be balanced with the actual energy consumption it is advisable to use U-values without a safety margin. In order to do this, adjusting the wind velocity is one possible approach. If values below the normative 4 m/s are used, the result will be lower values for h_e. The extent to which the U-value itself is corrected depends on the thermal quality of the element. As shown in Fig. 2 the reduction of the U-value is found to be between 2 (low U-values) and 20 % (high U-values). Example calculations for four existing, uninsulated buildings show that the adjusted U-values (with a wind velocity of 0 m/s) improve by 8 % on average. This leads to a reduction of the heating demand by 4 to 8 %.

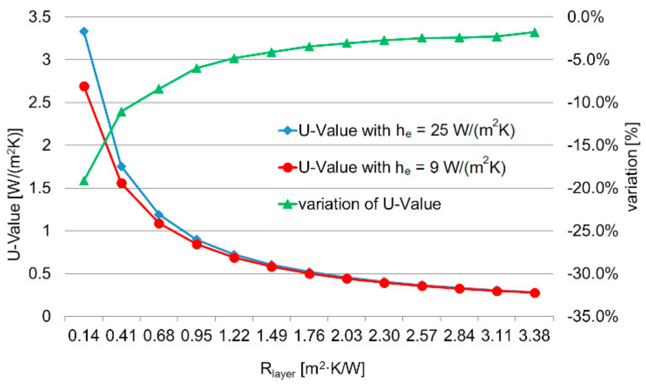


Fig. 2: U-values with different heat transfer coefficients exterior on the basis of different wind velocities (refer to table x). h_e = 25.0 or 9.0 W/(m^{2}K), h_i = 8 W/(m^{2}K).

4.2. Temperatures of basements with uninsulated cellar ceiling

The temperature measurements in six basements showed a spread of only approx. 0.5 – 2.5 K. This allows the conclusion that the basement temperatures of randomly selected buildings are quite similar. The minimal measured basement temperature is 13 °C, the temperature calculated according to [4] is significantly lower. The calculated temperatures shown in Fig. 1 (b) are found for a basement with a basement floor 2 m below ground level. The best boundary condition for minimal thermal losses would be a basement entirely below ground level. The worst case would be a basement with walls exposed to ambient air. The calculated mean temperature for the best and the worst cases are 0.7 K apart.

For the basement used as example, the calculated b-value is 0.78, the corresponding temperature is 8.3 °C (boundary condition: normative outdoor temperature for Basel-Binningen, mean of the heating period 5.1 °C Oct-

Mar). The calculated b-factor is close to the default values proposed by SIA 380/1:2015 for unheated cellars (0.7 cellar full-faced to ground, 0.8 cellar partly faced to ground).

In order to find out which b-factor corresponds to the lowest measured temperature of 13°C an iterative approach based on the procedure according to [4] is necessary. The corresponding b-factor found is 0.51.

It is important to use reasonable indoor air temperatures of unheated building zones for heating demand calculations. Especially for existing buildings when the cellar ceiling is uninsulated the indoor air temperature assumed for the cellar determines the calculated heat loss through this component. If a balancing of demand and consumption of the heating energy is done and measured cellar temperatures are not available, we suggest using a b-factor of 0.5. Naturally, this is only applicable for uninsulated, existing buildings of the type described in chapter 2.2. The reduction in the heating demand if measured indoor temperatures are used instead of calculated ones is between 5 and 10 %.

5. Conclusions

The prebound-effect as the gap between performance and actual energy consumption in existing buildings may have several reasons. In this paper we focus on two aspects: U-values and indoor air temperatures of unheated basements.

It is shown that measured U-values for uninsulated building components are often lower (“better”) than the calculated values (12-111%). This is at least in part due to an intentional safety margin for the boundary conditions within the standardized calculation procedure. In this paper we propose adjusting the wind velocity used in the external heat transfer coefficient as method to reduce the safety margin. U-values calculated in this way should be used exclusively if a balancing of demand and consumption of the heating energy is done. For calculations of the heating load and analysis´ in the context of mould protection and humidity control maintaining the safety margin is essential.

Temperature measurements in basements of existing buildings reveal considerably higher values (around 8 K) than a calculation according to applicable building codes would yield. Especially when the cellar ceiling is uninsulated the indoor air temperature assumed for the cellar determines the calculated heat loss of this component. Therefore, it is necessary to use reasonable cellar temperatures when demand / consumption alignment is of interest. We suggest the use of a b-factor of 0.5 for existing buildings with uninsulated cellar ceilings.

Of course, adjustments suggested here are usually not in agreement with building code compliance calculations.

Acknowledgements

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