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Conversion of unheated basements and the conditioning of their indoor climate

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Abstract. This paper deals with unheated basements in existing buildings. Due to soaring housing prices these rooms may be increasingly used for the storage of sensitive goods and temporarily for leisure activities. In order to keep these rooms free of mould various technical solutions are available. However, it is unclear whether they prevent mould growth and how high their energy demand is. This question is explored by simulating an unheated basement in an uninsulated, a renovated and a newly built building. Each basement can be operated in four modes: (1) natural ventilation, (2) an extract ventilation, which is activated according to the difference of partial vapour pressure between inside and outside (dampguard), (3) an air dehumidifier and (4) an electrical heating. The simulations with ESP-r are performed for three climates in Switzerland. Results confirm that in new buildings the probability of mould growth is negligible. In the other building types, mould growth can be prevented only with an air dehumidifier or a dampguard. However, only the latter process proves to be energy efficient. When assessing higher temperatures due to climate change in most cases the risk of mould growth remains unchanged and to a lesser extent increases or decreases.

1. Aim of Research

Unheated basements are increasingly used for the storage of sensitive goods (e. g. paper documents and clothes) and temporarily as studios to pursue leisure activities. Quite often, the basements are not fit for this conversion and therefore various technical equipment is implemented to prevent mould growth. However, these technical solutions may be common practice but are not energy efficient, often. This paper compares different operation modes of basements by the probability of mould growth and energy demand.

2. Scientific methodology

2.1. Assumptions for the building model

Three building standards are considered: Firstly, a more or less uninsulated basement (“uni”), secondly, a renovated basement with an insulated ceiling (“ren”) and thirdly, a newly built, entirely insulated basement (“new”), cf. Table 1. The lower half of the walls and the floor adjoins ground, the upper half of the wall the exterior. For the uninsulated and the renovated basements, the upper 80 cm of the wall are insulated. The ground slab has no sealing [1], whereas the walls are coated with bitumen. The ground floor above the basement is included into the simulation in order to take into account a potential impact of the basement operation on the adjacent rooms.

Four different modes to operate basements are compared.



- NatVent: a one-sided **natural ventilation** by a permanently tilted window (opening area 0.33 m²). This case is considered as a base case. The building site is assumed sheltered.
- DGuard: a “**dampguard**”, which activates extract ventilation when the partial vapour pressure inside exceeds the value outside. Depending on the basement’s type, the extract ventilation generates the following air change rates: 0.7 h⁻¹ (“uni”), 0.3 h⁻¹ (“iso”), 0.1 h⁻¹ (“new”). When the fan is switched on, fresh air passes into the room through an opening with a diameter of 0.12 m. The infiltration ranges from 0.06 h⁻¹ (“new”) to 0.12 h⁻¹ (cellar type “uni, iso”).
- ADehum: an **air dehumidifier** operating in a bandwidth between 30 and 50 % relative humidity. The dehumidifier is based on a recirculating airflow with an airflow rate of 510 m³/h. The infiltration is identical to “DGuard”.
- EHeat, an **electrical heating** with an on-setpoint of 14 °C and an off-setpoint of 18 °C. The infiltration is identical to “DGuard”.

Table 1. Building components for all three building standards. Abbreviations used: uni = uninsulated, ren = renovated, new = newly built, b = basement, g = ground floor

Component	Building standard	Sealing	U-Value W/(m ² K)	Component	Building standard	Sealing	U-Value W/(m ² K)	g-value %
Walls, b, uninsulated	uni, ren	yes	3.7	Ceiling, b	ren	no	0.32	
Walls, b, insulated	uni, ren, new	yes	0.17	Glazing, b, g	uni, ren	no	2.7	70
Walls, g	uni, ren, new	no	0.17	Glazing, b, g	new	no	0.89	60
Floor, b	uni, ren	no	0.59	Frame, b, g	uni, ren	no	2.7	
Floor, b	new	yes	0.17	Frame, b, g	new	no	1.4	
Ceiling, b	uni, new	no	1.4					

The basement has no internal loads and no moisture generation (e. g. by a tumble dryer). The ground floor is operated with internal loads and operation profiles according to SIA 2024:2015 [2] for housing.

For each building standard and the mode of operation the simulations are run with three different climate data sets. These represent a Swiss city climate (Zurich, ZH), a mountainous region (Davos, DA) and a southern climate (Locarno, LO). The climate data used are the Design Reference Years SIA 2028 [3] for a normal year. As a glance at a future warmer climate, the data for a warm year in each climate region are also considered. The data are provided by SIA 2028 and represent the months with the highest air temperatures during 1984 to 2003.

The simulations with ESP-r [4] take the transient one-dimensional heat- and moisture transfer in multi-layered constructions into account. The air flow is considered by means of a nodal air flow network.

2.2. Assumptions for the ground model

As the building is 1.25 m in-ground, each climate is represented by two specific profiles for ground temperatures: one for the walls and one for the ground slab, where a depth of 5.0 m is assumed to approximately take the height of the wall and the distance to the centre of the floor into account. The ground temperature profiles do not take the building into account.

For the uninsulated (“uni”) and the renovated basement (“ren”) the floor has no sealing. Consequently, the soil moisture must be considered. Soil moisture is measured at different stations in Switzerland. The type of soil at a site may vary on a small scale and it is unusual to focus on a specific soil type. As a general calculation approach WUFI [5], a widespread tool for assessing hygrothermal performance of buildings, uses a relative humidity of 99 % [6]. This approach is also used by [7]. The rationale behind this value may be explained with the following model. If we assume clay at a depth of 70 cm with a density of 1.5 g/m³ and compare it with the mean measured soil moisture of 0.4 m³ H₂O/m³ the result is a mean humidity of 0.27 kg H₂O/kg and a moisture content of μm 40 % by mass,

respectively. This value corresponds to a saturated state according to [8] (annex 2) and thus a moisture potential of 1.0, hence a relative humidity of near enough 99 %.

2.3. How heat and moisture transport is considered in ESP-r

The thermal simulation program ESP-r includes the one-dimensional heat and moisture transport in multilayer building components. Moisture transfer due to diffusion and moisture storage in materials in the range of the moisture potential $\Phi < 0.99$ (hygroscopic range) is considered. Data for the material properties (thermal characteristics, sorption data, vapour diffusion) are retrieved from [9] and [10]. The model takes the relative humidity outside and the soil moisture into account.

2.4. Evaluation of the results: mould growth and energy demand

For the growth of mould fungi, five determining factors are relevant:

- The humidity available to the micro-organism
- The temperature range favourable to the growth of different mould fungi
- Substrate (i. e. building material and / or degree of soiling)
- Duration of favourable growing conditions
- Other prerequisites like pH-value and light.

In [11] a method is put forward to evaluate potential mould growth by means of an isopleth system, which describes the hygrothermal prerequisites for germination and growth of mould taking into account the building component surface temperature, the relative humidity of adjacent air and the substrate. The isopleth system allows to indicate the germination time and the myzel growth for groups of common mould species under different boundary conditions. In this work, surfaces of substrate category II which include building materials with a porous structure such as renderings and mineral building substances are considered.

In addition, for each operation mode the energy demand is evaluated.

2.5. Simulation of three-dimensional heat transport with VOLTRA

The limitation to one-dimensional heat transport in ESP-r results in an incomplete consideration of the resulting temperatures in the junction of the ceiling and the basement wall (see also section 3.1). Therefore, a three-dimensional simulation is performed with VOLTRA [12] for the building type “uni” in the operation mode “NatVent” with climate data of “ZH”. In order to have a reasonable similarity between the two simulation models the air change rate for the basement and the interior temperatures for the ground floor are imported from ESP-r in hourly time steps into VOLTRA. Material data and dimensions are identical to the ESP-r simulation model. The dimensions of the earth block enclosing the lower part of the basement are chosen according to [13]. Basis for the comparison is the south facing wall.

3. Results obtained

3.1. Simulations with normal year DRY weather data

Table 2 presents the simulation results focusing on growth of mould fungi in the basement. The evaluation discriminates between summer and winter. As a general trend, the risk of mould germination and subsequent growth is higher in summer than in winter. Relating to the building standards, it is obvious that in the newly built building no risk of mould growth can be found, due to the all-over insulation of the building envelope. The most critical standard is the partly renovated basement with an insulated ceiling as only measure. This is because of the fact that the insulation reduces the heat transfer between the ground floor and the basement efficiently. Thus, temperatures in the basement with the insulated ceiling are lower compared to the basement with the bare ceiling. The probability of mould growth is not strongly dependent on the investigated climates. In fact, the effects of the operation mode on mould growth are stronger especially for the uninsulated and the renovated existing building. A risk of mould growth is found for the operation modes “NatVent” und “EHeat”. The operation modes “DGuard” and “ADehum” prevent mould growth for the investigated climates.

Table 2. Simulation results with focus on growth of mould fungi in the basement. Winter (15.10.-15.04.) and summer (16.04.-14.10.) are evaluated separately. Abbreviations used: wi = winter, su = summer, uni = uninsulated, ren = renovated, new = newly built, ZH = Zurich, LO, Locarno, DA = Davos. Interpretation: in the rows “mould growth wi /su the number after “Yes” indicates the number of the affected building components (external wall, slab adjoining ground, insulated / uninsulated wall adjoining exterior, internal wall, ceiling adjoining the ground floor

Growth of mould fungi substrate category II													
Climate		Zuerich (ZH) / Locarno (LO) / Davos (DA)											
Operation mode		Natural ventilation (NatVent)			Dampguard (DGuard)			Air dehumidifier (ADehum)			Electrical heating (EHeat)		
Heating		No			No			Yes, waste heat dehumidifier			Yes		
Recirculation ach [h ⁻¹]		-			-			max. 5.8			-		
Fresh air supply by		Tilted window (0.33 m ² clear area)			Exhaust ventilator			Infiltration			Infiltration		
Fresh air supply ach [h ⁻¹]		-			0.7	0.3	0.1	-	-	-	-	-	-
Fresh air supply window / infiltr. [h ⁻¹]		Variable (Nodal air flow network)			Mean 0.12		Mean 0.06	Mean 0.12		Mean 0.06	Mean 0.12		Mean 0.06
Basement type		uni	ren	new	uni	ren	new	uni	ren	new	uni	ren	new
ZH	Mould growth wi	No	No	No	No	No	No	No	No	No	No	Yes (3/6)	No
	Mould growth su	Yes (5/6)	Yes (4/6)	No	No	No	No	No	No	No	Yes (1/6)	Yes (2/6)	No
LO	Mould growth wi	No	No	No	No	No	No	No	No	No	Yes (2/6)	No	No
	Mould growth su	Yes (4/6)	Yes (4/6)	No	No	No	No	No	No	No	No	No	No
DA	Mould growth wi	No	Yes (1/6)	No	No	No	No	No	No	No	No	No	No
	Mould growth su	Yes (3/6)	Yes (4/6)	No	No	No	No	No	No	No	Yes (1/6)	Yes (1/6)	No

16.04.-14.10.	Maximal duration of exceeding germination time for substrate category II depending on temperature and humidity					
	LIM _{Bau,II} [d]	16 d [d]	8 d [d]	4 d [d]	2 d [d]	1 d [d]
Uni. wall adj. ground 1	44	42.5	32.5	31.4	30.8	19.2
Uni. wall adj. ground 2	44	42.5	32.5	31.5	30.9	15.3
Uni. wall adj. ground 3	44	42.5	32.5	31.4	30.8	15.1
Uni. wall adj. air 1	3	1.6	0.7	0.3	0.0	0.0
Uni. wall adj. air 2	1	0.5	0.0	0.0	0.0	0.0
Uni. wall adj. air 3	2	1.2	0.3	0.0	0.0	0.0
Iso. wall adj. air 1	23	20.6	7.5	7.2	6.6	6.0
Iso. wall adj. air 2	23	11.0	7.4	6.9	6.3	5.5
Iso. wall adj. air 3	23	20.5	7.5	7.0	6.4	5.6
Internal wall	23	21.3	11.3	7.8	7.5	7.0
Floor	134	132.6	131.4	125.0	124.0	101.4
Ceiling	7	6.3	5.4	4.5	3.0	2.3

Table 3. Maximal duration of exceeding germination time, summer, (“ZH/NatVent/ uni”). Abbreviations used: uni. = uninsulated, iso. = insulated, adj. = adjoining. Interpretation (3rd column, 4th row): 42.5 days is the maximal period, where the floor exceeds the conditions, at which the fungi spore needs 16 days for germination. Not specified: frequency of occurrence, here 1.

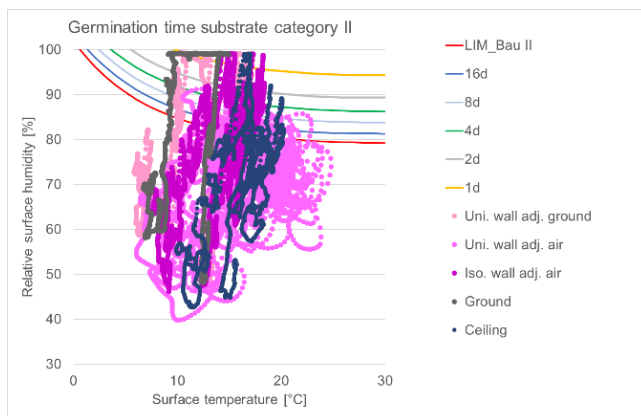


Figure 1. Potential for mould growth in summer (16.04 – 14.10.), “ZH/NatVent/ uni”. Abbreviations used: see Table 3. Interpretation: LIM_{Bau,II} is the lowest boundary line of possible fungus activity. This line is exceeded by all building components and mould growth can therefore be expected. Favourable conditions for germination within a day are reached by the floor, the ceiling, the uni. wall adj. ground and the iso. wall adj. air (and the internal wall, which is not depicted).

If the building components are compared to each other (Table 3 and Figure 1 for “ZH/NatVent/uni”) it can be observed that the insulated wall adjoining the ceiling is exposed to a higher risk of mould growth than the uninsulated wall beneath. This contradicts the recommendation that the base near the basement ceiling should be insulated [14] in order to reduce thermal bridging. The phenomenon can be

explained by the fact that the simulation model is one-dimensional and adjoining building components don't interact thermally directly (only indirectly via the adjacent air). For further information see also section 3.3.

Evaluation of the energy demand proves "EHeat" to be the most energy demanding option. Resulting demands range from 70 ("LO/uni") to 330 kWh/(m²a) ("DA/iso"). This is also true when the reduction of the heating demand of the ground floor is taken into account (-15 %, basis of comparison "ZH/NatVent/uni"). Moreover, "EHeat" cannot prevent mould growth. An effective mould control is provided by "DGuard" und "ADehum". The energy demand for "ADehum" is quite high with values from 60 to 90 kWh/(m²a). "DGuard" in conjunction with the exhaust ventilation is very energy efficient, showing a electricity demand for the fan of only 0.2 kWh/(m²a) and therefore represents a quite reasonable solution.

3.2. Simulations with warm year DRY weather data

A comparison of the normal and the warm year for each climate shows that the difference of the yearly temperature mean varies from +3.5 ("ZH") and +3.0 ("DA") to +2.3 K ("LO"). The yearly mean of the absolute humidity in the warm year is also always higher than in the normal year: +15 % in "DA", +10 % in "ZH" and +7 % in "LO". Comparison of the warm and normal years in regard to the potential for mould growth, only the operation modes "NatVent" and "EHeat" differ. The differences concentrate on the building types "uni" and "ren", the new building remains mould free. Table 4 compares both years. With the operation mode "NatVent" mould growth remains constant or affects less building components. With "EHeat", mould growth affects more building components, suggesting that even with the elevated temperatures outside the electrical heating (restricted to 18 °C) and the air infiltration of 0.12 h⁻¹ do not prevent mould growth effectively. As in the normal year, the operation modes "ADehum" and "DGuard" ensure mould free building components in the warm year, as well. Although a reduction in the energy demand could be expected, this is only true for the operation mode "EHeat", that ranges from 30 kWh/(m²a) for "LO/uni" to 250 kWh/(m²a) for "DA/iso". This is a reduction by -24 % and -57 %. "ADehum" varies from 60 to 90 kWh/(m²a), thus remaining constant. This also applies to the most energy efficient operation mode "DGuard".

Table 4: Simulation results with focus on growth of mould fungi in the basement with climate data for a warm year. Winter (15.10.-15.04.) and summer (16.04.-14.10.) are evaluated separately. The arrows compare the results of the warm year with the normal year (Table 2). Abbreviations used: see table 2. ↔ = same mould growth in both years, ↑ = more building components affected, ↓ = less building components affected. For interpretation of the numbers after "yes" see Table 2.

	NatVent				EHeat			
	uni		ren		uni		ren	
	winter	summer	winter	summer	winter	summer	winter	summer
Mould ZH warm	No	Yes (5/6)	No	Yes (4/6)	No	Yes (1/6)	Yes (1/6)	Yes (1/6)
Increase / decrease ZH	↔	↔	↔	↔	↔	↔	↓	↓
Mould LO warm	No	Yes (1/6)	No	Yes (4/6)	Yes (4/6)	Yes (4/6)	No	Yes (4/6)
Increase / decrease LO	↔	↓	↔	↔	↑	↑	↔	↑
Mould DA warm	No	Yes (2/6)	No	Yes (4/6)	Yes (5/6)	Yes (4/6)	Yes (1/6)	Yes (2/6)
Increase / decrease DA	↔	↓	↓	↔	↑	↑	↑	↑

3.3. Three-dimensional simulations with VOLTRA

Simulations with VOLTRA reveal that the inside surface temperature of the insulated wall (19.6 °C) approximates that of the uninsulated wall (19.7 °C) in July. The temperature for the insulated wall exceeds the calculated surface temperature with ESP-r (17.7 °C, respectively 20.2°C for the uninsulated wall. Basis for comparison: south oriented wall). Evaluation of mould growth for the south wall based on the temperatures obtained by VOLTRA does not show any risk in summer or winter for the case

considered (cf. Table 3, Iso. Wall adj. air 1). A more detailed insight into the comparison of the one- and three dimensional simulation approach will be presented elsewhere.

4. Conclusion

Based on simulations, unheated basements in existing buildings are compared using different operation modes to avoid mould growth. The simulations are performed for different building standards and for different Swiss climates. The results suggest the following recommendations for unrenovated and renovated buildings with an insulated cellar ceiling without any user-induced moisture loads:

- A permanent one-sided natural ventilation cannot be recommended. Neither is it an effective mould protection, nor is it energy efficient. This is also true for the temperature control of the basement with an electric heating. The latter proves to have an unreasonable high energy demand. Air dehumidification is to be assessed as critical: On one hand it enables an efficient mould protection, on the other hand the energy demand is very high.
- Climate control with a dampguard is found to be the most effective mould control with a quite reasonable energy demand.

In order to provide a glance at a future, warmer climate, additional simulations were performed with climate data for warm years. For the two operation modes “NatVent” and “EHeat” and the associated building types “uni” and “ren”, which have a risk of mould growth, the comparison shows that in most cases the potential of mould growth remains unchanged (winter: 7 of 12 cases, summer: 5/12). To a lesser extent, the risk of mould growth increases (winter: 3/12, summer 4/12) or decreases (winter 2/12, summer: 3/12).

A comparison of a one-dimensional with a three-dimensional simulation approach supports the notion that the insulation in the upmost third of a basement wall does not increase the risk of mould growth on this particular surface.

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