



Máté Orosz

Time-dependent changes  
in building energy performance of  
ultra-lightweight concrete panel constructions

PhD Theses

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2017

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## 1. THE AIM OF THE DISSERTATION

The cold-formed steel structures are cost-efficient lightweight constructions that are widely used in industrial as well as in residential buildings. However, in case of these constructions the building physical requirements, the thermal insulation capability, vapor barrier, airtightness, acoustical requirements, must be fulfilled with additional building components separately from the loadbearing structure. This problem can be eliminated by using a composite system of optimized polystyrene aggregate concrete and cold-formed steel structure. This construction can be even more cost-efficient, since the polystyrene concrete can provide continuous bracing for the steel elements. Recently, comprehensive researches were conducted about the stability behavior of ultra-lightweight concrete encased cold-formed steel structures with promising results.

The aim of this dissertation is to investigate the construction from building physical and building energy perspectives, and analyze its applicability in different climatic conditions.

## 2. METHODOLOGY OF THE RESEARCH

Firstly, the ultra-lightweight concrete was investigated in laboratory and the hygrothermal properties were determined. Then, based on results of laboratory tests 2D dynamic conjugated heat and moisture simulations were carried out to determine the *effective thermal transmittance* of the wall and roof constructions and the *effective linear thermal transmittance* of structural connections (wall corner, loadbearing wall - roof connection, wall - ground connection) in different climates. To investigate the moisture load of the wall panel with different plasters ( $s_d$ -values), 1D hygrothermal simulations were conducted. The simulated thermal transmittance value of wall panel and the results of a calibrated whole building simulation were compared to in-situ measurements in Hungary to validate the models (Figure 1.)

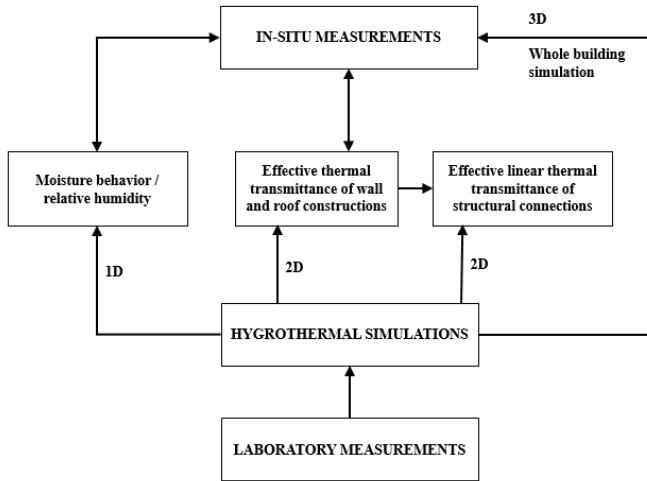


Figure 1. Methodology of research

## 2.1. Laboratory measurements

The laboratory measurements were conducted in the Building Physics Laboratory of the Department of Architectural Engineering (MET-LAB) at the Budapest University of Technology and Economics.

The thermal conductivity values were measured by a *Taurus TLP 300 DTX* thermal conductivity measuring instrument with guarded hot plate, and the declared values were determined according to the MSZ EN ISO 10456:2008 standard.

The sorption and desorption isotherms were determined with a *Labmaster AW* water activity measuring instrument and a precision scale with dryer according to the principles of MSZ EN ISO 12571:2013 standard.

The water absorption was measured according to the MSZ EN ISO 15148:2003.

The building physical parameters describing the vapor permeability of the ultra-lightweight concrete were investigated according to the MSZ EN ISO 12572:2001.

## 2.2. Dynamic hygrothermal simulation based on finite volume method

In this research a widely used and validated software tool, the WUFI software (Wärme Und Feuchte Instationär), was applied, that is based on the following two differential equations: heat transport (1.), moisture transport (2.):

$$\frac{\partial H_m}{\partial T} \frac{\partial T}{\partial t} = \nabla(\lambda \nabla T) + h_v \nabla(\delta \nabla(\varphi p_{sat})) \quad (1)$$

$$\frac{\partial w}{\partial \varphi} \frac{\partial \varphi}{\partial t} = \nabla(D_\varphi \nabla \varphi + \delta \nabla(\varphi p_{sat})) \quad (2)$$

where  $H_m$  [J/m<sup>3</sup>] is the enthalpy of moist building material;  $T$  [K] is the temperature;  $\lambda$  [W/mK] is the thermal conductivity of moist material;  $h_v$  [J/kg] is the evaporation enthalpy of the water;  $\delta$  [kg/msPa] is the water vapor diffusion coefficient of the material;  $\varphi$  [-] is the relative humidity;  $p_{sat}$  [Pa] is the saturation vapor pressure;  $w$  [kg/m<sup>3</sup>] is the water content;  $D_\varphi$  [kg/ms] is the moisture conduction coefficient;  $\nabla$  is vector differential operator.

The software applies *finite volume method* to solve the differential equations. This method applies conservative discretization, i.e. algebraic equations are derived from the differential equations, while the heat and moisture balances are preserved in every element of numerical grid. The flowchart of hygrothermal simulations are shown in Figure 2.

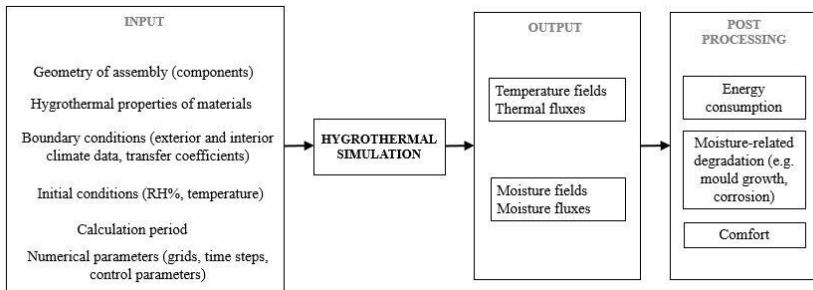


Figure 2. Flowchart of hygrothermal simulations

### 2.3. Pearson's correlation

To investigate the effect the interior boundary condition on heat flux density at the wall-ground connection, Pearson's correlation was applied. The Pearson's correlation coefficient is a statistical measure expressing the strength of relationship between two variables. If there are two data sets  $X=\{x_1, \dots, x_n\}$  and  $Y=\{y_1, \dots, y_n\}$ , where  $n$  is the number of the data, the correlation coefficient is:

$$R(X, Y) = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (3)$$

where  $\bar{x}$  and  $\bar{y}$  are the sample means.

### 2.4. Kriging method

The moisture content within the wall panel was determined in discrete points (in every cm), and in every hour of the investigated year. Based on these data set, continuous surface was created by applying *Kriging*. *Kriging* is a flexible gridding method, and grid node values are calculated from the neighboring data points, in a way, that every point is weighted by its distance from the calculated node.

### 2.5. In-situ measurement of thermal transmittance

The heat flow meter method of in-situ thermal transmittance measurements is described in the ISO 9869-1:2014 standard.

The  $U$ -value can be calculated by dividing the mean heat flux density by the mean temperature difference; and, to obtain accurate results, the measurement should last at least 72 hours (3 days).

### 3. PRINCIPAL SCIENTIFIC RESULTS (THESES) (Chapter 8.1.)

The new scientific results are written in bold, the explanations are written with normal characters.

#### I. HYGROTHERMAL BEHAVIOR OF THE ULTRA LIGHTWEIGHT CONCRETE

##### **Thesis I./1.** [2] [6]

According to the MSZ EN ISO 10456:2008 standard the temperature conversion of thermal conductivity of building materials should be determined by an exponential function. **Based on laboratory measurements I introduced a linear approximation function to determine the temperature conversion factor of the investigated ultra-lightweight concrete, that gives as accurate estimation as the exponential function of the standard does in case of 10-35 °C:**

$$F_T = 0.001(T_2 - T_1) + 1.0 \quad (4)$$

where  $F_T$  [-] is the temperature conversion factor and  $T_1, T_2$  [°C] are temperature values.

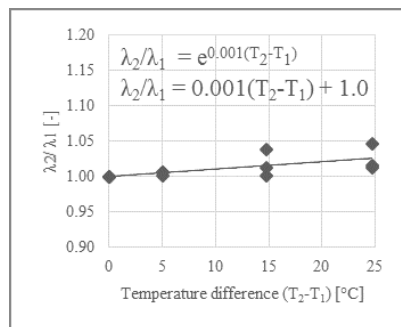


Figure 3. Approximation of temperature conversion according to the MSZ EN ISO 10456:2008 (dashed line) and the linear approximate function (continuous line – overlapping)

**Thesis I./2.** [2] [6]

According to the MSZ EN ISO 10456:2008 standard the moisture conversion of thermal conductivity should be determined by an exponential function. **Based on laboratory measurements I demonstrated, than in case of the investigated ultra-lightweight concrete, the exponential approximation required by the standard does not estimate the moisture dependency of thermal conductivity accurately ( $R^2 = 0.16$ ), and I introduced a natural logarithm function that approximates it with higher precision before capillary condensation phase, in case of minimum 0.12 m% moisture content ( $R^2=0.82$ ):**

$$F_m = 0.0486 \cdot \ln(u) + 1.1288 \tag{5}$$

where  $F_m$  [-] is the moisture conversion factor;  $u$  [m%] is the moisture content mass by mass.

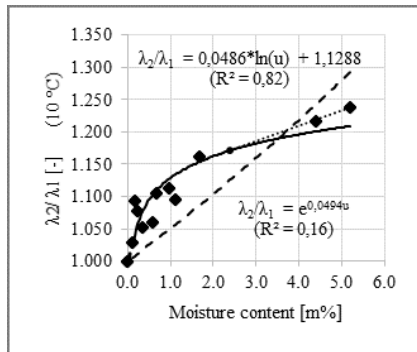


Figure 4. Approximation of moisture conversion according to the to the MSZ EN ISO 10456:2008 standard (dashed line), and the new approximate function (continuous line)



Applying this function along with the inverted sorption isotherm, **I determined that the multi-molecular layer is developed at 24% RH, and at this relative humidity level the  $F_m$  moisture conversion factor is 1.13 [-]. Furthermore, I determined that the capillary condensation begins at 67% RH, and at this relative humidity level the  $F_m$  moisture conversion factor is 1.17 [-].**

I created a diagram (Figure 5) that allows to determine the moisture conversion factor of thermal conductivity of the investigated ultra-lightweight concrete at any relative humidity level before the capillary condensation phase (between 1% RH and 67 % RH).

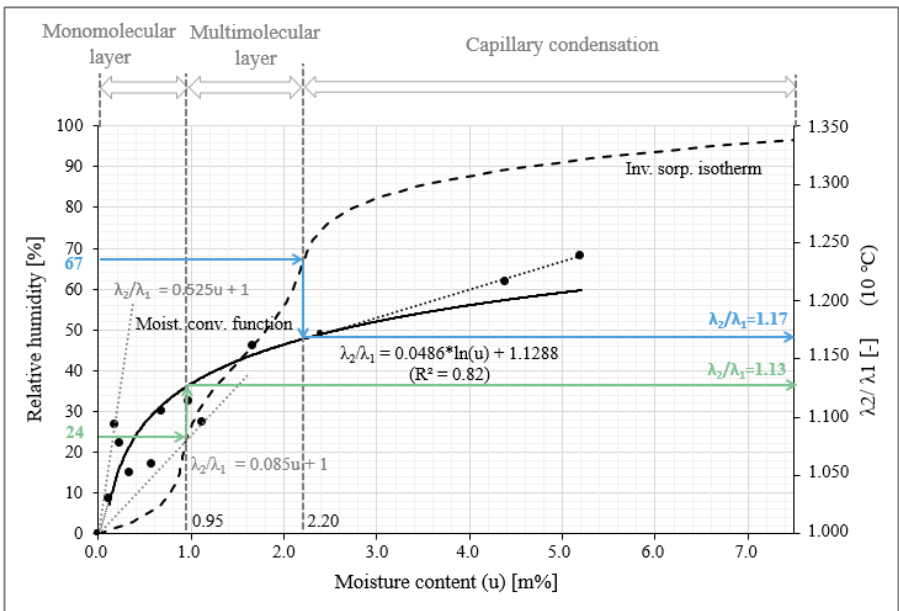


Figure 5. Moisture conversion function (continuous line) along with the inverted sorption isotherm (dashed line)

**Thesis I./3.** [2] [6]

The sorption/desorption diagrams depend on temperature. However, **based on laboratory measurements, I demonstrated, that in case of the investigated ultra-lightweight concrete, the temperature has an impact mainly on the shape of desorption diagram: the lower the temperature, the higher the moisture content at a certain relative humidity level.**

**Based on laboratory measurements, I introduced fifth-degree polynomial functions to approximate the sorption as well as the desorption isotherms of the investigated ultra-lightweight concrete with high precision at temperature of 23°C ( $R_S^2=0.95$ ,  $R_{DS}^2=0.90$ ):**

$$u_{sorp} = 2 \cdot 10^{-8} \cdot \varphi^5 - 4 \cdot 10^{-6} \cdot \varphi^4 + 0.0003 \cdot \varphi^3 - 0.0098 \cdot \varphi^2 + 0.149 \cdot \varphi \quad (6)$$

$$u_{desorp} = 2 \cdot 10^{-8} \cdot \varphi^5 - 5 \cdot 10^{-6} \cdot \varphi^4 + 0.0005 \cdot \varphi^3 - 0.0166 \cdot \varphi^2 + 0.2881 \cdot \varphi \quad (7)$$

where  $u$  [m%] is the water content;  $\varphi$  [%] is the relative humidity.

Applying these equations, **comparing the monomolecular, multimolecular and capillary condensation phases, I demonstrated that the standard deviation of measured moisture content [m%] increases with increasing relative humidity. Moreover, I demonstrated that the standard deviation is higher in case of desorption.** (Figure 6)

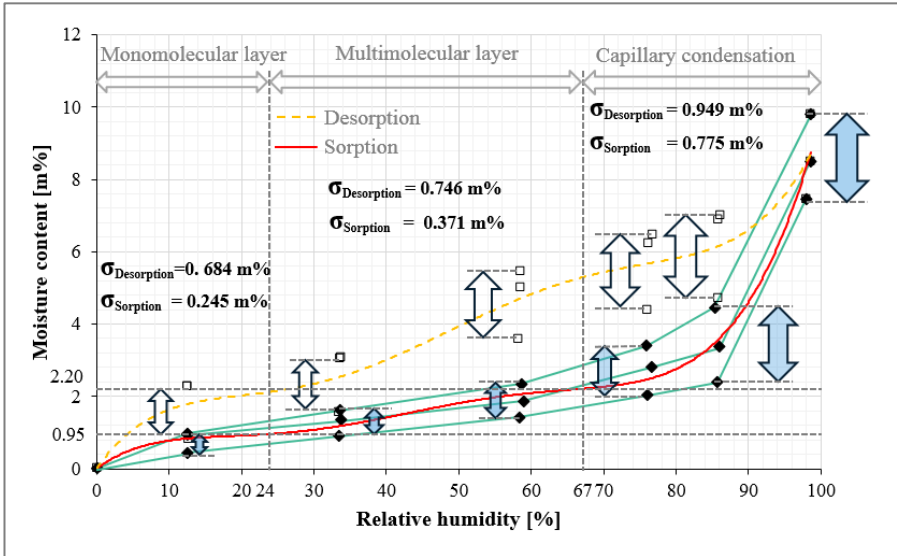


Figure 6. Standard deviation of the measured moisture content

## II. ADAPTATION OF IN-SITU THERMAL TRANSMITTANCE MEASUREMENT FOR SIMULATION RESULTS

### Thesis II./1. [3]

I adapted the average method of in-situ measurement of thermal transmittance declared in the ISO 9869-1:2014 standard for results of dynamic conjugated heat and moisture transfer simulations. **Applying my new method, I determined the effective thermal transmittance ( $U^*$ ) [W/m<sup>2</sup>K] values of the investigated ultra-lightweight concrete wall and roof constructions for three periods: the heating season, October and July (Figure 7); for humid continental (Espoo, Finland), temperate continental (Budapest, Hungary) and mediterranean (Lisbon, Portugal) climate, considering the 2012-2014 time period.**

**I concluded that the  $U^*$ -value of the investigated ultra-lightweight concrete wall panel in the period of October-March (2013-2014) is higher by 13.5% in humid continental climate, and 23.9% in temperate continental climate than the steady-state  $U_{stac}$ -value; however, it is smaller by 17.4% in mediterranean climate.**

**I also concluded that the  $U^*$ -value of the investigated ultra-lightweight concrete roof construction, in the period of October-March, is almost equal to the steady-state  $U_{stac}$ -value in humid continental climate (higher by 0.6%); it is higher by 7.1% than  $U_{stac}$  in temperate continental climate, and it is smaller by 21.2% in mediterranean climate.**

Based on my results, in case of detailed thermal examination of building constructions, the climate-dependent *effective thermal transmittance* ( $U^*$ ) determined by my new the method is suggested applying; since use of the steady-state  $U_{stac}$  -value often can result in an outcome, that is even significantly different from the actual behavior of the construction.

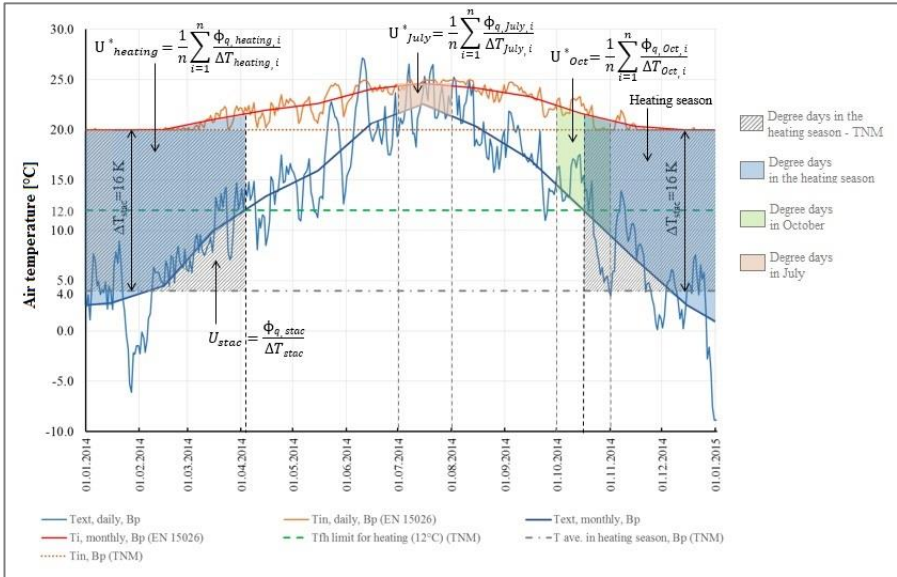


Figure 7. Calculation of effective thermal transmittance from simulation results

**Thesis II./2.** [3] [4]

Applying my new method, I determined the *effective linear thermal transmittance* ( $\Psi^*$ ) [W/mK] values for the structural connections (wall corner, load-bearing wall-roof and wall-ground connections) of the investigated ultra-lightweight concrete construction for three periods: the heating season, October and July; for humid continental (Espoo, Finland), temperate continental (Budapest, Hungary) and mediterranean climate (Lisbon, Portugal), considering the 2012-2014 time period.

I concluded that the  $\Psi^*$ -value at the investigated ultra-lightweight concrete wall corner, in the period of October-March (2013-2014), is lower by 21.9% in humid continental climate, 15.6% in temperate continental climate, and 90.6%

**in mediterranean climate than the steady-state  $\Psi_{stac}$ -value.** (In mediterranean climate it is nearly zero.)

**However, at the loadbearing wall - roof connection the  $\Psi^*$ -value is higher than the steady-state value in every investigated location: by 68.0% in humid continental, 8.0% in temperate continental, and 52.0% in mediterranean climate.**

**At the wall - ground connection the  $\Psi^*$ -value is significantly lower than steady-state value, its 33% in Espoo, 40% in Budapest, and 34% in Lisbon.**

**Furthermore, in case of the investigated wall-ground connection, in the period of October - March (2013-2014) the dynamic simulation results in significantly smaller heat loss than the steady-state calculation; the heat loss coefficient is smaller by 45.8% in Espoo, 38.3 % in Budapest and 61.6 % in Lisbon.**

Based on my results, in case of detailed thermal examination of building constructions, the climate-dependent *effective linear thermal transmittance* ( $\Psi^*$ ) determined by my new the method is suggested applying; since use of the steady-state  $\Psi_{stac}$  -value often can result in an outcome, that is even significantly different from the actual behavior of the construction.

### III. MOISTURE LOAD OF ULTRA-LIGHTWEIGHT CONCRETE WALL PANEL

#### **Thesis III.** [1] [5]

**Based on dynamic conjugated heat and moisture transfer simulations, I found that the maximum moisture content of the ultra-lightweight concrete wall panel – in humid continental (Espoo, Finland) and temperate continental (Budapest, Hungary) climate as well as in mediterranean climate (Lisbon, Portugal) – depends significantly on the  $s_d$ -value of the exterior plaster, but it does not depend significantly on the  $s_d$ -value of the interior surface.**

**Based on the results of simulations, I recommend the following types of exterior plasters for the investigated ultra-lightweight concrete wall panel according to the climate:**

- **Temperate continental climate (Budapest, Hungary):**  
Exterior plaster with “high”  $s_d$ -value  
– 3 mm acrylic plaster ( $s_d = 0.575$  m)
- **Humid continental climate (Espoo, Finland):**  
Exterior plaster with “medium”  $s_d$ -value  
– 2 mm silicone plaster ( $s_d = 0.300$  m)
- **Mediterranean climate (Lisbon, Portugal):**  
Exterior plaster with “high” or “medium”  $s_d$ -value  
– 3 mm acrylic ( $s_d = 0.575$  m) or 2 mm silicone ( $s_d = 0.300$  m) plaster

On interior surface 1 cm thick gypsum plaster ( $s_d = 0,100$  m) or vapor barrier and gypsum boards on wood studs ( $s_d = 100.150$  m) is recommended.

Under the acrylic and silicone plasters 4 mm thick adhesive mortar layer ( $\mu=50$ ) was assumed.

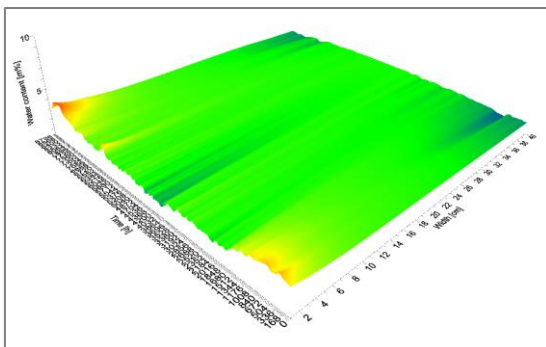
**BUDAPEST – B1**

Exterior:

“high”  $s_d$  (0.575 m)

Interior:

“low”  $s_d$  (0.100 m)



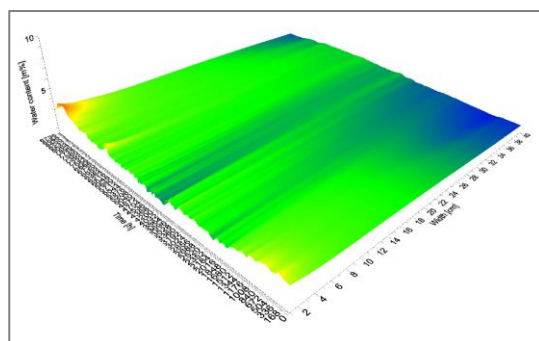
**BUDAPEST – B7**

Exterior:

“high”  $s_d$  (0.575 m)

Interior:

“high”  $s_d$  (100.150 m)



**BUDAPEST – B9**

Exterior:

“low”  $s_d$  (0.122 m)

Interior:

“high”  $s_d$  (100.150 m)

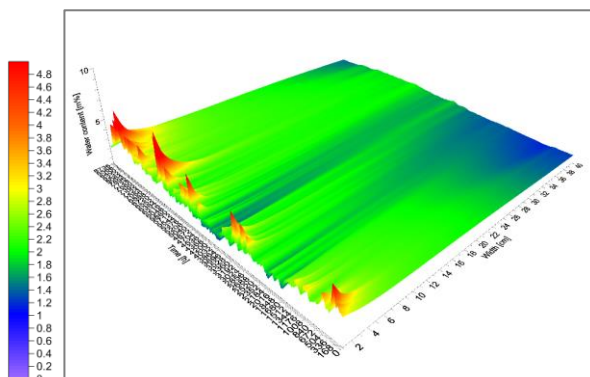


Figure 8. Moisture content [m%] of the ultra-lightweight concrete wall panel with different types of exterior and interior surfaces in Budapest (Hungary)



## 4. Utilization of results and further research questions

The method presented in the dissertation can be used to calculate the specific heat loss coefficient more accurately in case of a building construction; furthermore to determine the length of heating season, and also to investigate the risk of overheating in summer. The advantage of this method comparing to a not simplified dynamic hygrothermal simulation is that if the *effective heat transfer coefficient* ( $U^*$ ) and the *effective linear heat transfer coefficient* ( $\Psi^*$ ) are determined for a given construction for a given period of time (e.g. heating season), the specific heat loss coefficient can be calculated without conducting expensive, time-consuming and expertise-demanding dynamic simulations.

The *effective thermal transmittance* ( $U^*$ ) and the *effective linear thermal transmittance* ( $\Psi^*$ ) for the heating season is necessary to determine the specific heat loss coefficient ( $q$ ) accurately.

According to the *TNM 7/2006 (V.24.) Decree* the specific heat loss coefficient can be calculated by the following formula:

$$q = \frac{1}{V} \left( \sum AU + \sum l\Psi - \frac{Q_{sd} + Q_{sid}}{72} \right) \quad [\text{W}/\text{m}^3\text{K}] \quad (8)$$

where  $A$  [ $\text{m}^2$ ] is the interior surface,  $U$  [ $\text{W}/\text{m}^2\text{K}$ ] is the thermal transmittance ( $U_{stac}$ );  $l$  [ $\text{m}$ ] is the length of thermal bridge at a structural connection,  $\Psi$  [ $\text{W}/\text{mK}$ ] is the linear thermal transmittance ( $\Psi_{stac}$ );  $Q_{sd}$  [ $\text{W}$ ] is the direct solar energy gain;  $Q_{sid}$  [ $\text{W}$ ] is the indirect solar energy gain,  $V$  [ $\text{m}^3$ ] is the heated volume of the building.

According to the simplified calculation method, the heating season is between October 15<sup>th</sup> and April 15<sup>th</sup>. The  $U$ -value applied in the formula was determined for this period by steady-state calculation ( $U_{stac}$ ). This value is different from the *effective thermal transmittance* ( $U^*_{heating}$ ) due to the following main reasons:

- The  $U_{stac}$  and  $U^*_{heating}$  belongs to different degree days:  $U_{stac}$  belongs to 72 000 [hK/a]; while in case of  $U^*_{heating}$ , the hourly calculated and summed degree days are considered.
- The hygrothermal properties of the investigated building construction change according to the exterior and interior environmental conditions, and this is not considered while calculating  $U_{stac}$ .

Calculation of the *effective thermal transmittance* ( $U^*$ ) for October is necessary to determine the length of the heating season. In Budapest (Hungary) the exterior air temperature falls below the limit temperature for heating (12°C) in October. To determine the length of the heating season, according to the detailed calculation method, this month should be investigated; however, the beginning of the heating season depends on the characteristics of the building, the solar heat gain, as well as the internal heat gain.

Calculation of the *effective thermal transmittance* ( $U^*$ ) for July is necessary to investigate the risk of overheating in summer, since in Budapest (Hungary) the average daily temperature is the highest in July.

The analysis of moisture load of ultra-lightweight concrete wall panel allows selecting the proper interior/exterior plasters, surface design according to the current climate, minimizing the risk of vapor condensation within the construction, and thus, increasing the durability.

The accuracy of results can be increased by conducting 3D simulations of structural connections, and taking air filtration through construction into consideration.

Considering the longer service life expectancy of this newly developed construction, possible corrosion of steel structural elements should also be investigated in a further research.

## 5. MAGYAR NYELVŰ ÖSSZEFOGLALÓ (TÉZISEK) (Chapter 9.1.)

A tézisek kiemelten, a rövid magyarázatok normál betűtípussal szerepelnek.

### I. AZ ULTRA-KÖNNYŰ BETON HIGROTERMIKUS VISELKEDÉSE

#### **Tézis I./1.** [2] [6]

A jelenleg hatályos MSZ EN ISO 10456:2008 szabvány szerint az építőanyagok hővezetésének hőmérsékleti konverzióját exponenciális függvénnyel kell közelíteni.

**Laboratóriumi mérésekre alapozva, a vizsgált ultra-könnnyűbeton esetére bevezettem egy lineáris összefüggést, ami ugyanolyan pontosan közelíti a hőmérsékleti konverziós együtthatót 10-35 °C között, mint a szabvány szerinti exponenciális függvény.**

$$F_T = 0.001(T_2 - T_1) + 1.0 \quad (4)$$

ahol  $F_T$  [-] a hőmérsékleti konverziós együttható, és  $T_1$ ,  $T_2$  [°C] a hőmérsékleti értékek.

#### **Tézis I./2.** [2] [6]

A jelenleg hatályos MSZ EN ISO 10456:2008 szabvány szerint az építőanyagok hővezetésének nedvesség konverzióját exponenciális függvénnyel kell közelíteni.

**Laboratóriumi mérésekkel kimutattam, hogy a vizsgált ultra-könnnyűbeton esetére a szabvány által előírt exponenciális függvény pontatlanul közelíti a hővezetés értékét ( $R^2 = 0.16$ ), és bevezettem egy természetes alapú logaritmus függvényt, amely pontosabban közelíti a hővezetés nedvességfüggését a kapilláris kondenzációs fázis előtt, minimum 0.12% nedvességtartalom esetén ( $R^2 = 0.82$ ):**

$$F_m = 0.0486 \cdot \ln(u) + 1.1288 \quad (5)$$

ahol  $F_m$  [-] a nedvesség konverziós együttható;  $u$  [m%] a nedvességtartalom (tömegarányra).

Felhasználva ezt a függvényt és az inverz szorpciós izotermát, **meghatároztam, hogy a multi-molekuláris réteg 24% relatív páratartalomnál alakul ki, és ezen relatív páratartalom esetén az  $F_m$  nedvességkonverziós együttható 1.13 [-]. Továbbá meghatároztam, hogy a kapilláris kondenzáció 67% relatív páratartalomnál kezdődik, és ekkor az  $F_m$  nedvességkonverziós együttható 1.17[-].**

Létrehoztam egy diagramot (Figure 5), amelynek segítségével meghatározható a vizsgált ultra-könnyű beton hővezetési tényezőjének nedvesség konverziós együtthatója bármely relatív páratartalom esetén a kapilláris kondenzációs fázis előtt (1% és 67% relatív páratartalom között).

### **Tézis I./3.** [2] [6]

A szorpciós/deszorpciós diagramok hőmérséklet-függők. Ugyanakkor, laboratóriumi mérésekkel kimutattam, **hogy a vizsgált ultra-könnyűbeton esetében a hőmérsékletnek elsősorban a deszorpciós diagram alakjára van hatása: minél alacsonyabb a hőmérséklet, annál magasabb a nedvességtartalom adott relatív páratartalom mellett.**

**Laboratóriumi mérések alapján, ötödfokú polinomiális függvényeket vezettem be a vizsgált ultra-könnyűbeton szorpciós és a deszorpciós izotermáinak pontos közelítésére 23 °C esetén ( $R_S^2=0.95$ ,  $R_{DS}^2=0.90$ ):**

$$u_{sorp} = 2 \cdot 10^{-8} \cdot \varphi^5 - 4 \cdot 10^{-6} \cdot \varphi^4 + 0.0003 \cdot \varphi^3 - 0.0098 \cdot \varphi^2 + 0.149 \cdot \varphi \quad (6)$$

$$u_{desorp} = 2 \cdot 10^{-8} \cdot \varphi^5 - 5 \cdot 10^{-6} \cdot \varphi^4 + 0.0005 \cdot \varphi^3 - 0.0166 \cdot \varphi^2 + 0.2881 \cdot \varphi \quad (7)$$

ahol  $u$  [m%] a nedvességtartalom;  $\varphi$  [%] a relatív páratartalom.

Alkalmazva ezeket az egyenleteket, a **monomolekuláris, multimolekuláris és kapilláris kondenzációs fázisokat összehasonlítva kimutattam, hogy a mért nedvességtartalom [m%] értékek szórása a relatív páratartalom növekedésével növekszik. Továbbá kimutattam, hogy a szórás nagyobb deszorpció esetén.** (Figure 6).

## II. HELYSZÍNI HŐÁTBOCSÁTÁSI TÉNYEZŐ MÉRÉS ADAPTÁCIÓJA SZIMULÁCIÓS EREDMÉNYEKRE

### Tézis II./1. [3]

Az ISO 9869-1:2014 szabvány szerinti helyszíni hőátbocsátási tényező mérésnél alkalmazott átlag módszert adaptáltam dinamikus kapcsolt hő- és nedvességtranszport szimulációk eredményire. **Az általam bevezetett módszert alkalmazva meghatároztam a vizsgált ultra-könnyű beton fal- és tetőszerkezetre az *effektív hőátbocsátási tényező* ( $U^*$ ) [ $W/m^2K$ ] értékét három időszakra: a fűtési időnyre, októberre és júliusra (Figure 7); nedves kontinentális (Espoo, Finnország) mérsékelt kontinentális (Budapest, Magyarország) és mediterrán (Lisszabon, Portugália) éghajlaton, a 2012-2014 éveket figyelembe véve.**

**Megállapítottam, hogy a vizsgált ultra-könnyű beton falpanel  $U^*$ -értéke az október-márciusi időszakot (2013-2014) tekintve a nedves kontinentális éghajlaton 13.5%-kal, a mérsékelt kontinentális éghajlaton 23.9%-kal magasabb, mint az állandósult állapotra meghatározott  $U_{stac}$ -érték, ugyanakkor mediterrán éghajlaton 17.4%-kal alacsonyabb.**

**Megállapítottam továbbá, hogy vizsgált ultra-könnyű beton tetőszerkezet  $U^*$ -értéke az október-márciusi időszakot tekintve, a nedves kontinentális**

**éghajlaton közel egyelő (0.6%-kal magasabb), a mérsékelt kontinentális éghajlaton 7.1%-kal magasabb, mint az állandósult állapotra meghatározott  $U_{stac}$ -érték, ugyanakkor mediterrán éghajlaton 21.2%-kal alacsonyabb**

Az eredményeim alapján, az épületszerkezetek részletes hőtechnikai vizsgálata során az általam javasolt módon meghatározható, és éghajlatonként is eltérő, *effektív hőátbocsátási tényező*vel ( $U^*$ ) célszerű számolni; ugyanis az állandósult állapotra meghatározott  $U_{stac}$ -érték alkalmazásával a szerkezet tényleges viselkedését sok esetben kevésbé közelítő, attól akár jelentősen eltérő eredményekre is juthatunk.

### **Tézis II./2.** [3] [4]

**Az általam bevezetett módszert alkalmazva, a vizsgált ultra-könnyű betonból tervezett épületszerkezeti csomópontokra (falsarok, teherhordó fal-tetőszerkezet és fal-padló csatlakozás) meghatároztam az *effektív vonalmenti hőátbocsátási tényező* ( $\Psi^*$ ) [W/mK] értékét három időszakra: a fűtési időnyre, októberre és júliusra; nedves kontinentális (Espoo, Finnország) mérsékelt kontinentális (Budapest, Magyarország) és mediterrán (Lisszabon, Portugália) éghajlaton, a 2012-2014 éveket figyelembe véve.**

**Megállapítottam, hogy a vizsgált ultra-könnyű betonból tervezett falsarokhoz tartozó  $\Psi^*$ -érték az október-márciusi időszakot tekintve (2013-2014), a nedves kontinentális éghajlaton 21.9%-kal, a mérsékelt kontinentális éghajlaton 15.6%-kal, a mediterrán éghajlaton pedig 90.6%-kal alacsonyabb (közel nulla értékű), mint az állandósult állapotra meghatározott  $\Psi_{stac}$ -érték.**

**Ugyanakkor a teherhordó fal - tetőszerkezet csomópont esetében a  $\Psi^*$ -érték magasabb, mint állandósult állapotban mindhárom vizsgált helyszínen: nedves kontinentális éghajlaton 68.0%-kal, mérsékelt kontinentális ághajlaton 8.0%-kal, mediterrán éghajlaton pedig 52.0%-kal.**

**A fal-padló csatlakozásnál a  $\Psi^*$ -érték szignifikánsan alacsonyabb, mint az állandósult állapotbeli érték, Espooban annak 33%-a, Budapesten 40%-a, Lisszabonban 34%-a. Továbbá, a vizsgált fal-padló csatlakozásnál az október-márciusi (2013-2014) időszakot figyelembe véve, dinamikus szimulációval jelentősen kisebb hőveszteséget kapunk, mint stacioner számítással; a hőveszteség tényező Espooban 45.8%-kal, Budapesten 38.3%-kal és Lisszabonban 61.6%-kal kisebb.**

Az eredményeim alapján, az épületszerkezetek részletes hőtechnikai vizsgálata során az általam javasolt módon meghatározható, és éghajlatonként is eltérő, *effektív vonalmenti hőátbocsátási tényező*kkal ( $\Psi^*$ ) célszerű számolni; ugyanis az állandósult állapotra meghatározott  $\Psi_{stac}$ -érték alkalmazásával a szerkezet tényleges viselkedését sok esetben kevésbé közelítő, attól akár jelentősen eltérő eredményekre is juthatunk.

### III. AZ ULTRA-KÖNNYŰ BETON FALPANEL NEDVESSÉG- TERHELÉSÉNEK ELEMZÉSE

#### **Tézis III.** [1] [5]

**Dinamikus kapcsolt hő- és nedvességtranszport szimulációk alapján megállapítottam, hogy az ultra-könnnyű beton falpanel maximális nedvességtartalma – mérsékelt kontinentális (Budapest, Magyarország), nedves kontinentális (Espoo, Finnország) és mediterrán éghajlaton (Lisszabon, Portugália) egyaránt – jelentősen függ a külső vakolat  $s_d$ -értékétől, de nem függ jelentősen a belső felület  $s_d$ -értékétől.**

**A szimulációs eredmények alapján, a vizsgált ultra-könnnyű beton falpanelre az éghajlatnak megfelelően az alábbi külső vakolattípusokat javaslom:**

- **Mérsékelt kontinentális éghajlaton (Budapest, Magyarország):**  
Kültéri vakolat „magas”  $s_d$ -értékkel  
– 3 mm akril vakolat ( $s_d = 0.575 m$ )
- **Nedves kontinentális éghajlaton (Espoo, Finnország):**  
Kültéri vakolat „közepes”  $s_d$ -értékkel  
– 2 mm szilikon vakolat ( $s_d = 0.300 m$ )
- **Mediterrán éghajlaton (Lisszabon, Portugália):**  
Kültéri vakolat „magas” vagy „közepes”  $s_d$ -értékkel – 3 mm akril vakolat ( $s_d = 0.575 m$ ) vagy 2 mm szilikon vakolat ( $s_d = 0.300 m$ )

Belső felületképzésnek 1 cm vastagságú gipszes vakolatot ( $s_d = 0.100 m$ ) javaslak, vagy párazáró fóliát és gipszkarton burkolatot favázon ( $s_d = 100.150 m$ ).

Az akril és szilikon vakolatok alatt 4 mm vastagságú ragasztóhabarcs réteget ( $\mu=50$ ) feltételeztem.



## 6. LIST OF PUBLICATIONS IN THE TOPIC OF THE DISSERTATION

- [1] Orosz M.: *Time-dependent degradation of building constructions* (in Hungarian, Épületszerkezetek avulása) In: Széll M. (Ed.) Sustainable energy in design and education of building constructions (in Hungarian: Fenntartható energetika az épületszerkezetek tervezésében és oktatásában), TERC Kereskedelmi és Szolgáltató Kft, ISBN 978 963 9968 32 5, Budapest (2012), pp. 148-155.
- [2] Orosz M., Nagy B. Tóth E. *Hygrothermal behavior of ultra-lightweight polystyrene concrete*, Pollack Periodica, Vol. 12, No. 2, 2017, pp. 53–66
- [3] Orosz M., Nagy B. Tóth E. *Hygrothermal simulations and in-situ measurements of ultra-lightweight concrete panels*, Pollack Periodica, Vol. 12, 2017 (under publication)
- [4] Orosz M., Csanaky J. E. *Estimating the thermal bridge at wall corners with artificial neural network*, Acta Technica Jaurinensis, Vol. 8, No. 3, 2015, pp. 230–239.
- [5] Orosz M. *Comparison of ETICS and ventilated cladding system in terms of hygrothermal loads of mineral wool in Middle-Europe*, In: Józsa János, Lovas Tamás, Németh Róbert (ed.), Proceedings of the Conference of Junior Researchers in Civil Engineering 2012, Hungary, 19/06/2012-20/06/2012. Budapest: Budapest University of Technology and Economics, 2012. pp. 158-162.
- [6] Orosz M. *Temperature and moisture dependent thermal conductivity of a polystyrene concrete wall panel*, (in Hungarian: *Polisztirolbeton falpanel hő- és nedvességfüggő hővezetése*) In: Bodzás Sándor (ed.) Műszaki Tudomány az Észak - Kelet Magyarországi Régióban 2015, Conference, Debrecen, Hungary, 11 June 2015, ISBN: 978-963-7064-32-6 pp. 114–119.
- [7] Dunai L., Tóth E., Nagy B., Orosz M. *Development of polystyrene concrete encased lightweight steel frame structures* (in Hungarian: *Könnyű acélváz erősítésű polisztirolbeton panelszerkezetek fejlesztése*), R+D Report, Task 8. Measurement of building physical parameters of structural joints (in Hungarian), Budapest, 2015.