MOISTURE PROTECTION OF RESIDENTIAL BUILDINGS INFLUENCE OF TYNES ON THE THERMAL-HUMIDITY REGIME OF THE BUILDING

Artashes Petrosyan[1], **Spartak Sargsyan**[1]*

[1] *National University of Architecture and Construction of Armenia, Yerevan, RA*

Abstract: *Moisture penetration into the building structures of residential buildings is caused by climatic conditions and has a negative impact on the operation of buildings. Since thermal insulation of structures directly increases the energy saving of buildings, it can also affect the energy saving of buildings, contribute to the durability of enclosing structures, reduce condensate zones, and reduce fuel consumption during measures to eliminate penetrating water vapor. Buildings in different climatic zones have different vapor permeability rates, which can have different effects on the physical condition and thermal properties of surrounding structures. Thermal insulation significantly reduces the intensity of thermal conductivity and heat transfer processes, reduces air and moisture permeability. The main goal of this study was to determine the construction the amount of steam passing through the structure due to its vapor permeability and its impact on the thermo-humidity regime of the building. The thermal and air-humidity conditions of two types of buildings widespread in the Republic of Armenia, 5-story tuff and 9-story RC panel cladding structures, were observed in different climatic zones of the republic. It has been proven that the type, thickness and installation method of thermal insulation material have different effects on the formation of condensate zones in external structures for different settlements of the Republic of Armenia. As a result of the research, it was found that in tuff cladding structures (in the cities of Yerevan, Gyumri, Hrazdan, Vanadzor and Sevan) a condensate zone forms, while in Kapan it does not. However, by using different types of thermal insulation materials, such a phenomenon can be avoided. Studies have shown that in order to ensure the required thermal resistance and avoid condensation in the mentioned cities, it is necessary to use a thermal insulation material with the minimum required thickness. The thickness of the foamed polystyrene thermal insulation layer in buildings with a tufa structure is: In Yerevan and Vanadzor - 5 cm, in Gyumri - 6 cm, in Hrazdan and Sevan - 7 cm, in Kapan - 4 cm, and in expanded polystyrene - 6 cm in Yerevan and Vanadzor, 8 cm in Gyumri, Hrazdan and Sevan, and 5 cm in Kapan. In the case of reinforced concrete panel construction, the thickness of expanded polystyrene will be 9 cm in Yerevan, 10 cm in Vanadzor, 11 cm in Gyumri, Hrazdan, and Sevan, and 8 cm in Kapan, in the case of expanded polystyrene: 7 cm in Yerevan, 8 cm in Vanadzor, 9 cm in Gyumri and Sevan, 10 cm in Hrazdan, and 7 cm in Kapan.*

Keywords: *air-vapor permeability, thermal insulation effect, minimum thickness of the insulation layer, energy efficiency of buildings, thermal load.*

Spartak Sargsyan*

E-mail: s.sargsyannuaca@gmail.com

Received: 14.12.2024
Revised: 15.01.2025
Accepted: 04.02.2025

Introduction

The provision of thermal comfort conditions in residential buildings is largely determined by the provision of thermo-humid conditions in them. In the external construction, the thermo-humid regime of buildings changes under the influence of indoor and outdoor temperature, humidity, and wind speed. In particular, in the case of currently widely used almost absolutely hermetic "metal-plastic windows", excess humidity occurs in the air inside the building. To avoid this phenomenon, many European countries suggest using a "warm ventilation device - window" [1] for forced air movement and preheating of the incoming air. Quantitative and qualitative temperature-regulating heating/cooling re-users of the incoming air are also used: two-pipe, three-pipe, etc. [2]. In the cold season, as a result of the vapor permeability process of the building, depending on the indoor air temperature, the temperature on the inner surface of the external construction can equal the dew point temperature, causing condensation on the inner surface of the enclosing structure, which will disrupt the humidity regime of the building. To avoid such an undesirable phenomenon, it will be necessary to increase the indoor air temperature by increasing the thermal capacity of the heating system, as well as the consumption of additional organic fuel with hazardous emissions. If there is no danger of condensation due to the high indoor air temperature, then as a result of vapor permeability, the relative humidity of the indoor air will inevitably increase, instead of the required 40-60%, it will be in the range between the amount of penetrating steam and the internal moisture barriers. This is also a transient phenomenon, since the internal thermo-humidity regime is disrupted [3]. To avoid this phenomenon, it is again required to increase the thermal load of the heating system. In each case, the required heat quantity in the heating system will increase, and therefore the fuel consumption, and the ecological hazard will increase accordingly. The theoretical and experimental study of the heat and moisture transfer in building walls has been the target of a lot of important research work [4-7].

Materials and Methods

Moisture penetration into the building significantly affects its air humidity and thermal regime, since the moistening of building materials leads to an increase in their thermal conductivity coefficient and therefore to an increase in heat losses. In addition, the sanitary and hygienic properties of the building structure and buildings deteriorate: the relative humidity inside the building increases, and consequently, the risk of fungus and mold formation as well as the durability of the structure significantly decreases. Moisture can penetrate the building in various ways: as a result of groundwater, atmospheric moisture, and its condensation in the structure, internal moisture releases from people are possible, and in some cases as a result of the technological process. A significant part of the moisture can be removed, but moisture caused by atmospheric moisture penetration and condensation in the structure can periodically accumulate due to improper air humidity and temperature regime of the building. It occurs due to the temperature difference between the indoor and outdoor air [8,9], due to the difference in partial pressures or elasticity of water vapor, since there is a difference in partial pressures, diffusion process of gases and vapors [9-11]. The amount of water vapor will be determined as follows [11]:

$$G = \frac{e_{in}-e_{out}}{R_{vp}^{res}}, \tag{1}$$

where e_{in}, e_{out} are the elasticity of water vapor on the inner and outer surfaces of a building structure Pa, R_{vp}^{res} is the vapor permeability resistance of the layer, m^2 h Pa/mg.

The resistance to vapor permeability will be determined [11,12] by:

$$R_{vp}^{res} = \frac{\delta}{\mu}, \tag{2}$$

where μ is the moisture permeability coefficient of the layer, mg/m h Pa, δ- is layer thickness, m.

Then, according to [11,12] the numerical values of the saturation pressures at external and internal temperatures are determined:

$$E=1.84 \cdot 1011 \quad e^{\frac{-5330}{273+t}}, \tag{3}$$

where e is the base of the logarithmic function, t is the external or internal air temperature.

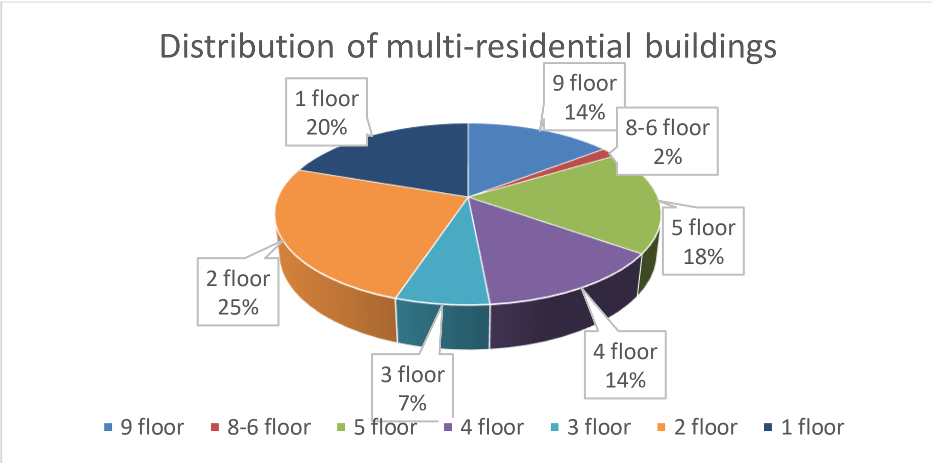
Having the indoor and outdoor saturation pressures and the numerical values of relative humidity, the specific laws of water vapor will be determined:

$$e_{in} = \frac{E_{in}}{\varphi_{in}}, \quad e_{out} = \frac{E_{out}}{\varphi_{out}}, \tag{4}$$

where E_{in}, E_{out} are the saturation pressures of the indoor and outdoor air, Pa, φ_{in}, φ_{out} are the relative humidities of indoor and outdoor air.

To prevent moisture condensation on the internal surface of a building structure, the following conditions must be met: E > e [9,13]. If this condition is not met, it is necessary to increase the thermal resistance of the structure by thermal or moisture insulation of enclosing structures. To select the necessary values in the above formulas and determine the calculated values, the parameters of the building are determined based on the thermo-humidity regime and the operating conditions of external building structures. Using the above methods, calculations were performed, and the results depending on the thermo-humidity regimes of the enclosing structures were determined for the cities of Yerevan, Gyumri, Kapan, Hrazdan, Vanadzor, and Sevan. Since the multi-apartment buildings of the main housing stock of the Republic of Armenia are 35-60 years old and the currently applicable energy efficiency standards did not exist during their construction, according to the calculations of various experts, the energy consumption per $1m^2$ of such buildings exceeds the same indicator in developed countries by about 30-50%, which is a consequence of the poor thermo-technical indicators of the enclosing structure.

According to studies[1], 56.1% of the apartments in the Republic of Armenia are located in cities, 43.9% in villages. About 70% of the total housing stock are private houses, and 30% are apartment buildings. About 70% of the external housing structures are made of stone, and 23% are panel buildings (Fig.1). According to the Cadastral Committee of the Republic of Armenia, the total area of the housing stock in the republic at the end of 2021 was 100.2 million m^2, including 55.9 million m^2 in cities and 44.3 million m^2 in villages. The distribution of 5- and 9-story buildings and their enclosing structures in 6 cities is also presented below[2].



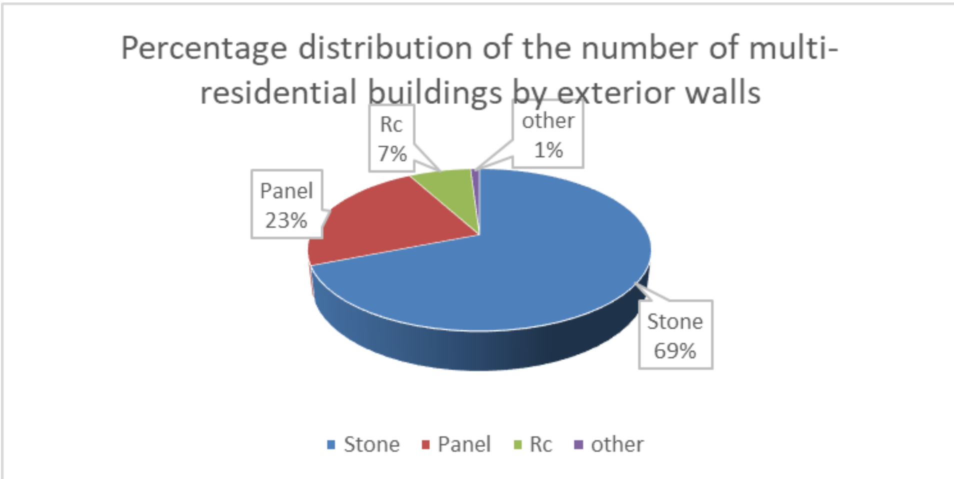


Fig. 1. *Distribution graphs of various buildings in the Republic of Armenia, 2021*

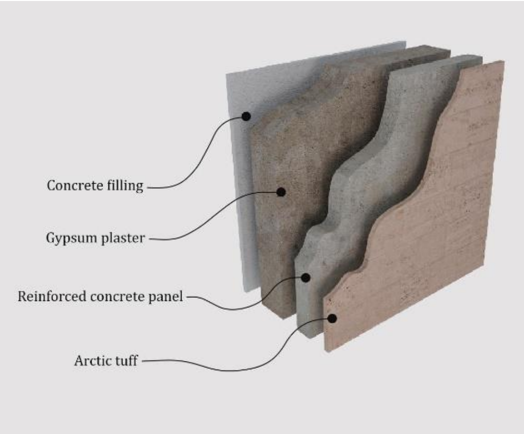
The cities mentioned above also have different climatic conditions which have a direct impact on the enclosing structures and their heat losses (Table 1).

Table 1. Outdoor air temperatures in cities during the heating season[3]

City	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Estimated outside air temperature, ^0C	-18	-19	-14	-14	-21	-9

[1] RA SC, Housing Stock and Public Utility in the Republic of Armenia.
[2] Ibid.
[3] "RA Construction Norms 22-01-2024 "Building Climatology". https://armmonitoring.am/page/1466

According to Figure 2, the calculation of the thermal resistance and heat transfer coefficient was carried out for the cladding structure.



Arctic tuff	$\delta_1 = 0.02m$,	$\lambda_1 = 0.52$ W/m^{0}C
Concrete filling	$\delta_2 = 0.1$m,	$\lambda_2 = 0.76$ W/m^{0}C
Reinforced concrete panel	$\delta_3 = 0.16$m,	$\lambda_3 = 1.92$ W/m^{0}C
Gypsum plaster	$\delta_4 = 0.02$m,	$\lambda_4 = 0.41$ W/m^{0}C

Fig. 2. *9 floor enclosing structure of a multi-story residential building*

Heat transfer resistance:

$$R_0 = \frac{1}{\alpha_{in}} + \frac{1}{R_s} + \frac{1}{\alpha_{out}} \quad , \tag{5}$$

where: α_{out} is the thermal conductivity coefficient of the external surface of the structure, W/m^2 ^{0}C,
α_{in} is the thermal conductivity of the internal surface of the structure, W/m^2 ^{0}C,
R_s is the thermal resistance of the enclosing structure, m^2 ^{0}C/W.

$$R_s = \frac{\lambda_1}{\delta_1} + \frac{\lambda_2}{\delta_2} + \frac{\lambda_3}{\delta_3} + \cdots + \frac{\lambda_n}{\delta_n} \quad , \tag{6}$$

where: λ_n is the calculated value of the thermal conductivity coefficient of the layer material, W/m ^{0}C,
δ_n is the layer thickness, m.

$$R_s = \frac{1}{23.2} + \frac{0.02}{0.52} + \frac{0.1}{0.76} + \frac{0.16}{1.92} + \frac{0.02}{0.41} + \frac{1}{8.7} = 0.46 \text{ m}^2\,{}^0\text{C/W}, \tag{7}$$

$$k_s = \frac{1}{0,46} = 2,17 \text{ W/m}^2\,{}^0\text{C} \tag{8}$$

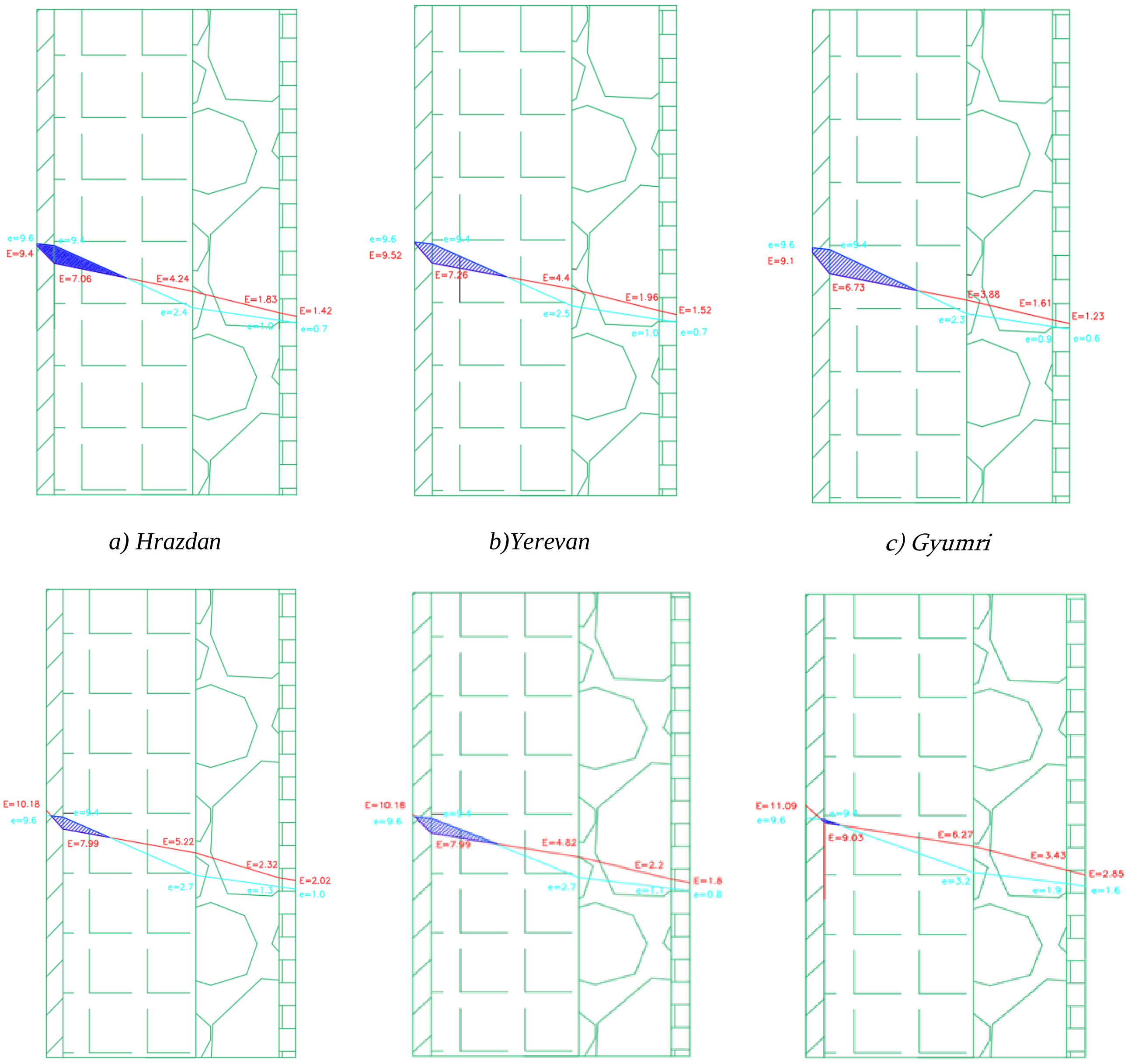
Accordingly, the heat losses of the building were calculated, and then the heat loads were determined under appropriate climatic conditions (Table 1), when the indoor air temperature is $t_{in} = 20^0$C. For each city, Table 2 provides the temperature and relative humidity of the outside air, saturation pressure, E, Pa, and mass amount of water vapor, mg/m^{2}h.

Table 2. Thermal load of a 9-story residential building and external air saturation pressure E, Pa, mass amount of water vapor, mg/m^{2}h

City / Calculated value	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Thermal load, kWt	178.1	182.8	159.4	159.4	194.0	135.9
Relative humidity of outside air, %	77	79	74	69	83	75
Saturation pressure of outside air E, Pa [6]	125.3	113.3	181.3	181.3	93.32	212.9
Mass amount of water vapor, mg/m^{2}h	168.9	170.7	160.8	160.8	173.6	145.8

Results and Discussion

To determine the mass amount of water vapor in the envelope, the relative humidity of the indoor air was assumed to be 55% [4]. Since the humidity is determined by the outdoor air temperature and is variable, the coefficient of elasticity for indoor air will be 2338 Pa [11]: The calculations of thermal loads were carried out according to the method[5], using conventional temperatures [9], and the mass amount of water vapor was calculated using the method given above (Fig.1). Figure 3 shows the graphs of the change in humidity due to moisture permeability in buildings in cities.



a) Hrazdan *b)Yerevan* *c) Gyumri*

d)Vanadzor *e) Sevan* *f) Kapan*

Fig. 3. *Graphs of humidity changes due to vapor permeability of a 9-story building*

[4] "Thermal Protection of Buildings" RACN 24-01-2016 https://nature-ic.am/en/publications/%22thermal-protection-of-buildings%22-racn-24-01-2016

[5] "RA Construction Norms II-7.02-1995 "Building Thermophysics of Fencing Constructions". https://www.minurban.am/storage/Normative/1-II-7.02-95%20.pdf

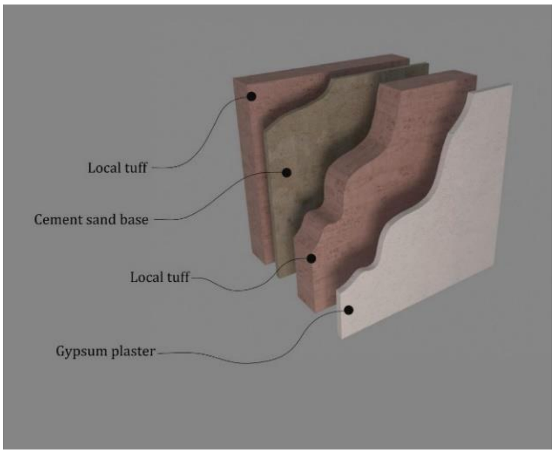
It follows from Figure 3 that in the given climatic zones, in the calculation mode, a condensate formation range can be obtained inside the enclosing structure. The latter largely depends on the calculation temperature of the external air and therefore on the vapor elasticity coefficient. As a result, the construction of buildings located in the given climatic zone. A condensate zone forms in the structure. As a result, the structure is subject to damage due to the resulting water ice. If it is close to the metal structure included in the structure, the metal will separate from the concrete and the structure will weaken, which is an undesirable or unacceptable phenomenon. This can be avoided if the outside of the structure is insulated with polystyrene foam when the minimum thickness of the insulation is: 9 cm in Yerevan, 10 cm in Vanadzor, 11 cm in Gyumri, Hrazdan, and Sevan, 8 cm in Kapan, and in the case of expanded polystyrene: 7 cm in Yerevan, 8 cm in Vanadzor, 9 cm in Gyumri and Sevan, 10 cm in Hrazdan, 6 cm in Kapan.

On the other hand, the massive flow of steam into the building endangers the sanitary condition of the internal structure - mold and unpleasant odors will appear. To avoid this, it is necessary to increase the temperature of the indoor air, and therefore the thermal load of the heating system, for the possible formation of condensate or evaporation of the penetrating steam. Increasing the load will lead to an increase in the power of the heat source and, therefore, an increase in the consumption of organic fuel. At the same time, it is necessary to increase the surfaces of the heating devices (Table 3).

Table 3. The effect of moisture permeability on fuel consumption

City / Energetic nature	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Gas consumption in January, m^3/month	20880	22263	20888	18210	18210	15532
Gas consumption in January, taking into account the effect of condensation, m^3/month	22350	24267	22768	19849	19483	16309

Then, the most common 5-story, tuff-lined, 2-entrance typical residential buildings in the Republic of Armenia were considered, for which the necessary thermal load and vapor permeability calculations were performed (Fig.4).



Local tuff $\delta_1 = 0.20$m, $\lambda_1 = 0.52$ W/m^{0}C

Cement sand base $\delta_2 = 0.08$m, $\lambda_2 = 0.76$ W/m^{0}C

Local tuff $\delta_3 = 0.20$m, $\lambda_3 = 0.52$ W/m^{0}C

Gypsum plaster $\delta_4 = 0.02$m, $\lambda_4 = 0.41$ W/m^{0}C

Fig. 4. *5 floor enclosing structure of a multi-story residential building*

The calculation was performed as before (formulas 5,6).

$$R_s = \frac{1}{23.2} + \frac{0.20}{0.52} + \frac{0.08}{0.76} + \frac{0.20}{0.52} + \frac{0.02}{0.41} + \frac{1}{8.7} = 1.23 \text{ m}^2\,{}^0\text{C/W}, \quad (9)$$

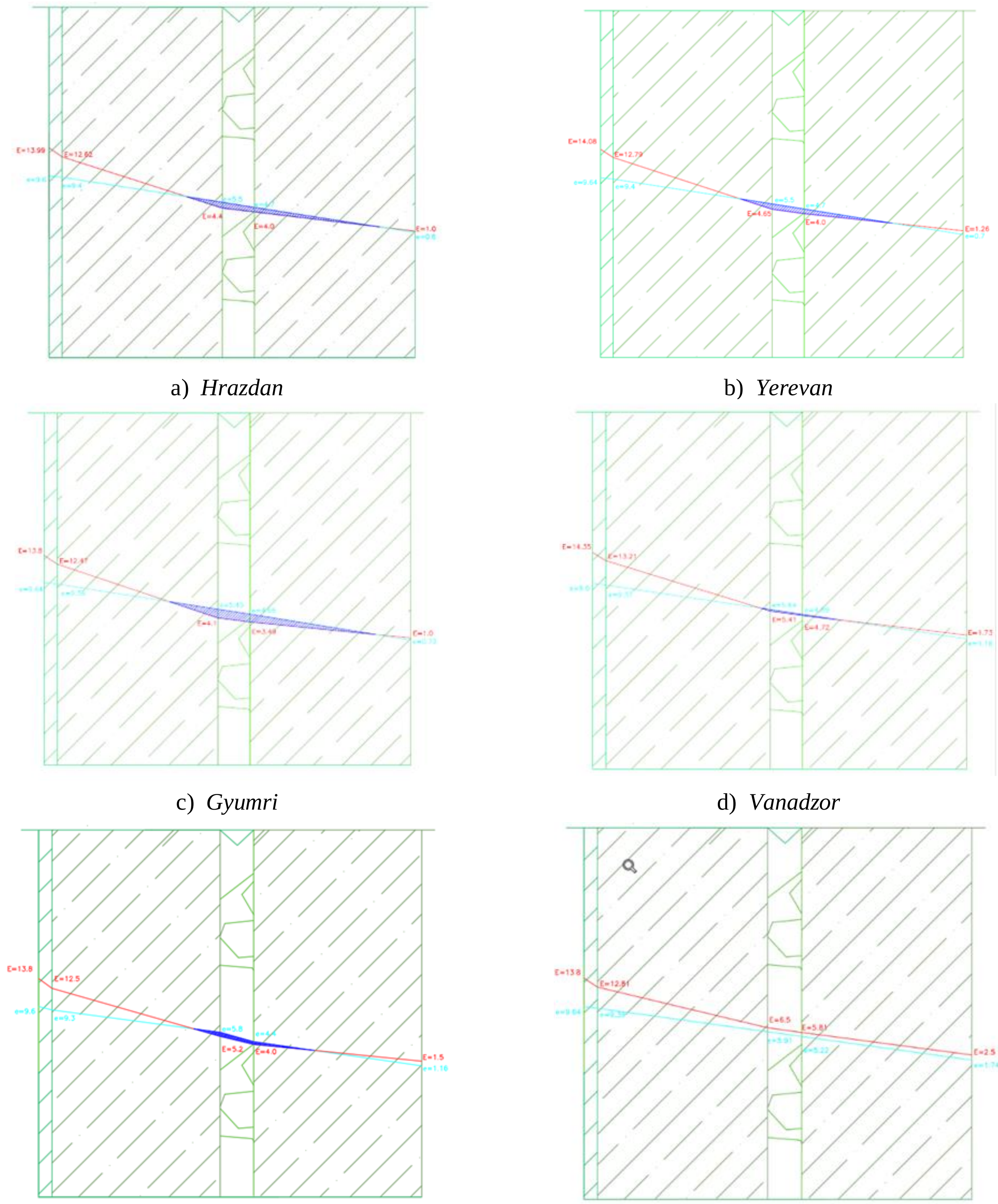
$$k_s = \frac{1}{1.23} = 0.92 \text{ W/m}^2\,{}^0\text{C}. \quad (10)$$

The outdoor air temperatures and relative humidity of a 5-story stone residential building, the heat load from the supporting structure inside, 20^0C, and the outdoor temperatures according to the calculated temperatures of the cities, the outdoor air saturation pressure E Pa, and the mass amount of water vapor, mg/m^{2}h are given in Table 4.

Table 4. Thermal load and saturation pressure of outdoor air and mass amount of water vapor of a 5-story residential building

City / Calculated value	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Thermal load, kWt	84.4	86.7	75.5	75.5	94.4	64.4
The relative humidity of the outside air, %	77	79	74	69	83	75
Saturation pressure of outside air E, Pa [11]	125.3	113.3	181.3	181.3	93.3	284.0
Mass of water vapor, mg/m^2h	214.8	216.1	208.0	209.7	218.3	193.8

Since moisture permeability for building construction is determined by the outside air temperature, the humidity change graphs in the calculation mode will be depicted in the form of Figure 5.



a) *Hrazdan* b) *Yerevan*

c) *Gyumri* d) *Vanadzor*

e) *Sevan* f) *Kapan*

Fig. 5. *Humidity change graphs due to vapor permeability of a 5-story building*

Figure 5 shows that for the city of Kapan, due to vapor permeability, there is no condensate formation zone. For the cities of Sevan and Vanadzor, the condensate formation zone is insignificant, but it falls on the clay-sand mortar. Since the duration of negative temperatures during the heating season is short, this zone cannot have a special effect. In the case of the cities of Hrazdan, Yerevan, and Gyur, such a zone falls on the clay-sand mortar itself, especially for Hrazdan, and represents a potential danger in terms of the formation of water ice and the destruction of the layer. In the climatic conditions of the city, the external tuff stone and the concrete mortar poured under it will weaken over time, and the weakening of the wall will be felt, especially on the upper 4th and 5th floors. As mentioned above, the area of condensation formation can be avoided by using a heat-insulating layer, especially in the climatic conditions of Hrazdan. In this case, the thickness of the heat-insulating layer, based on calculations, in the case of using foam-reinforced concrete, is 5 cm in Yerevan and Vanadzor, 6 cm in Gyumri, 7 cm in Hrazdan and Sevan, 4 cm in Kapan; in the case of thermal insulation with expanded polystyrene in buildings with a tufa structure, 6 cm in Yerevan and Vanadzor, 8 cm in Gyumri, Hrazdan and Sevan, 5 cm in Kapan.

Conclusion

1. Increasing the number of stories of a building leads to an increase of moisture permeability on the upper floors, especially in areas with cold climates, as the influence of gravitational forces and relative humidity in the outside air increases.
2. The negative and dangerous effects of moisture permeability can be avoided by insulating the exterior structure, depending on the building's thermal properties, geographical location, climatic conditions, barometric pressure, moisture buildup inside the building, etc.
3. The amount of moisture that penetrates due to moisture permeability can be avoided if a layer of heat- and moisture-insulating material is applied as close as possible to the outside of the structure.
4. The appropriateness of the above measures largely depends on the current and prospective fuel prices in the region.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

References

[1]. M. Tryjefaczka, Performance of Filters has the top Priority in the Air-conditioning (AC) Inspections. REHVA, 2011, 26-31.

[2]. A.L. Petrosyan, Energy Economic Suitability of the use of "Air-Air" Recuperators with Ribbing of Pipes for Exhaust Air. Proceedings of the 12th International Conference on Contemporary Problems of Architecture and Construction, Saint Petersburg, Russia, Nov. 25-26, 2020. Doi: https://doi.org/10.1201/9781003176428

[3]. V.N. Bogoslovskiy, Osnovy teorii potentsiala vlazhnosti materiala primenitel'no k naruzhnym ograzhdeniyam obolochki zdaniy. Moscow State University of Civil Engineering, 2013.

[4]. V.P. De Freitas, V. Abrantes, P. Crausse, Moisture Migration in Building Walls - Analysis of the Interface Phenomena. Building and Environment, 31 (2), 1996, 99–108. Doi: https://doi.org/10.1016/0360-1323(95)00027-5

[5]. L. Pel, K. Kopinga, H. Brocken, Moisture Transport in Porous Building Materials. Heron, 41(2), 95-105.

[6]. J. Wyrwa, A. Marynowicz, Vapour Condensation and Moisture Accumulation in Porous Building Wall. Building and Environment, 37 (3), 2002, 313-318. Doi: https://doi.org/10.1016/S0360-1323(00)00097-4

[7]. M. Matilainen, J. Kurnitski, O. Seppänen, Moisture Conditions and Energy Consumption in Heated Crawl Spaces in Cold Climates. Energy and Buildings, 35 (2), 2003, 203-216. Doi: https://doi.org/10.1016/S0378-7788(02)00051-8

[8]. B.N. Golubkov, T.M. Romanova, V.A. Gusev, Proyektirovaniye i ekspluatatsiya ustanovok konditsionirovaniya vozdukha i otopleniya. Energoatomizdat, Moscow, 1988 (in Russian).
[9]. V.N. Bogoslovskiy, Stroitel'naya teplofizika (teplofizicheskiye osnovy otopleniya, ventilyatsii i konditsionirovaniya vozdukha). Vysshaya Shkola, Moscow, 1982 (in Russian).
[10]. K. Shpaydel', Diffuziya i kondensatsiya vodyanogo para v ograzhdayushchikh konstruktsiyakh. Stroyizdat, Moscow, 1985 (in Russian).
[11]. R.V. Shchekin, S.M. Korenevskiy, G.Ye. Bem, F.I. Skorokhod'ko, Spravochnik po teplosnabzheniyu i ventilyatsii (v.1). Budivelnik, Kiyev, 1976.
[12]. K.F. Fokin, Stroitel'naya teplotekhnika ograzhdayushchikh chastey zdaniy. AVOK Press, Moscow, 2006 (in Russian).
[13]. F.V. Ushkov, Teploperedacha ograzhdayushchikh konstruktsiy pri fil'tratsii vozdukha. Stroyizdat, Moscow, 1969 (in Russian).

Artashes Petrosyan, Doctor of Philosophy (PhD) in Engineering, Associate Professor *(RA, Yerevan)* - *National University of Architecture and Construction of Armenia, lecturer at the Chair of Heat and Gas Supply and Ventilation, artashespetrosyan@mail.ru*

Spartak Sargsyan, researcher (Engineering) *(RA,Yerevan)* - *National University of Architecture and Construction of Armenia, lecturer at the Chair of Heat and Gas Supply and Ventilation, s.sargsyannuaca@gmail.com*