AN INVESTIGATION ON COMPATIBILITY PROPERTIES OF EXTERIOR FINISH COATS FOR INSULATED WALLS IN TERMS OF WATER VAPOUR PERMEABILITY AND MODULUS OF ELASTICITY

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ABSTRACT

AN INVESTIGATION ON COMPATIBILITY PROPERTIES OF EXTERIOR FINISH COATS FOR INSULATED WALLS IN TERMS OF WATER VAPOUR PERMEABILITY AND MODULUS OF ELASTICITY

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The compatibility properties of some contemporary finish coats together with their complementary layers used in insulated exterior walls were examined in terms of water vapour permeability and modulus of elasticity.

Basic physical and mechanical properties of some synthetic-, cement- and polymer-based external finish coats were analyzed in laboratory. Some additional samples, complementing the wall section, were also examined for their water vapour permeability.

Results showed that the finish coats were high vapour permeable although they had high resistance to water vapour permeation, which was achieved by their

application in thin layers. Cement-based undercoats were found to be medium permeable. The application of primer and/or paint was found to decrease the permeability of finish coats in different ranges. Thermal insulation layer was found to interrupt water vapour flow considerably. Among polystyrene- and mineral-wool-based thermal insulation boards, rockwool was recommended as the insulation layer due to its medium vapour permeability. In conclusion, walls insulated externally with rockwool boards and plastered with polymer-based finish coat, *FC8ACB* or synthetic-based finish coat *FC3SB* were found to be the most proper combination in terms of breathing and thermal resistance capabilities. All finish coats seemed to have sufficient strength and except the synthetic-based finish coat, *FC2SB*, they seemed to be compatible with each other and with the masonry in terms of their E_{mod} values. Further studies were recommended on some other compatibility properties of finishing systems, such as thermal and moisture dilatation properties, and on the relation between the resistance to water vapour permeation and water permeability.

Keywords: Finish coat, compatibility, water vapour permeability, modulus of elasticity, insulated external walls.

ÖZ

YALITIMLI DIŞ DUVARLARDA KULLANILAN CEPHE KAPLAMALARININ SU BUHARI GEÇİRİMLİLİK VE ESNEKLİK MODÜLÜ ÖZELLİKLERİ AÇISINDAN UYUMLULUKLARI ÜZERİNE BİR ÇALIŞMA

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Bu çalışmada günümüz dış cephe kaplamalarından bazıları ısı yalıtımlı dış duvarları oluşturan diğer yapı malzemeleriyle birlikte incelenmiş, su buharı geçirimlilik ve esneklik modülü değerleri açısından birbirleriyle uyumlulukları tartışılmıştır.

Sentetik, polimer ve çimento esaslı dış cephe kaplamalarının bazı temel fiziksel ve mekanik özellikleri laboratuvar analizleriyle belirlenmiştir. Bunun yanında içten ve dıştan yalıtımlı dış duvar kesitlerinde kullanılan katmanların da su buharı geçirimlilik özellikleri çalışılmıştır. Bu amaçla kaplama sistemini oluşturan çimento

esaslı alt katmanlar, astar ve boya katmanları ve duvar sistemini tamamlayan ısı yalıtım katmanlarının su buharı geçirimlilikleri incelenmiştir.

Sonuçlar dış cephe kaplamalarının su buharı aktarımına karşı yüksek dirence sahip olduklarını ve ancak ince katmanlar halinde uygulanmalarında yüksek geçirimli tabakalar oluşturduklarını göstermiştir. Ancak astar ve boya uygulaması bu kaplamaların su buharı geçirimliliklerini düşürmüştür. Kesitte dış cephe kaplamasının altında kullanılan çimento esaslı sıvalar ise orta geçirimli bulunmuştur. Isı yalıtım katmanının duvar kesitlerindeki su buharı akışını yüksek derecede kestiği gözlenmiştir. Polistren ve mineral yün esaslı ısı yalıtım levhaları karşılaştırıldığında orta geçirimli bir katman olduğu belirlenen taşyününün kullanılması önerilmiştir. Sonuç olarak, nefes alma özellikleri ve ısı dirençleri dikkate alındığında, polimer esaslı *FC8ACB* veya sentetik esaslı *FC3SB* ile kaplanmış, taşyünü levhalarla dışardan yalıtılmış dış duvar kesitlerinin en uygun çözüm olduğu belirtilmiştir. Esneklik modülleri açısından bütün kaplamaların yeterli dayanıma sahip oldukları ve sentetik esaslı *FC2SB* dışındaki tüm kaplamaların birbirleriyle ve duvar malzemesiyle uyumlu oldukları düşünülmüştür. Son olarak, bu malzemelerin ısı ve nem dilatasyon özellikleleri gibi diğer uyumluluk özelliklerinin de çalışılması önerilmiştir. Su buharı geçirimliliğine direnç ve su geçirimliliği arasındaki ilişki de çalışılması önerilen başka bir konudur.

Anahtar kelimeler: Dış cephe kaplamaları, uyumluluk su buharı geçirimliliği, esneklik modülü, yalıtımlı dış duvarlar.

TO MY BROTHER

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TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

CHAPTER 1

INTRODUCTION

In this chapter, the case for the study and specific end results sought are presented in the following sections; “argument” and “objectives”, which are followed up with progressed procedure and disposition of the rest of the study.

1.1 Argument

External walls are one of the most important components of the building construction due to their facing to the exterior. Finish coats are the final coats of external walls directly exposed to the effects of weathering conditions such as wetting and drying cycles, freezing and thawing cycles, heating and cooling cycles and salt crystallization cycles due to the changes in temperature and humidity, solar radiation, rain, wind and atmospheric gasses (Bochen, Stanislaw and Szwabowski, 2005; Caner, 2003; Williams and Williams, 1994). They have, therefore, important roles in a wall construction which should serve as a selective filter resisting to and protecting walls from external conditions and mitigating the effects of condensation. Besides, they conceal the unevenness in the background and provide a surface that is smooth, hygienic and aesthetic (Gürdal and Acun, 2004; Fassina, Favaro, Naccari and Pigo, 2002; Pfeifer, Ramcke, Achtziger and Zilch, 2001; Taylor, 1991; BRE, 1973). In addition, they may be required to improve fire

resistance, sound and thermal insulation, selection of which, in fact, depends on the specifications of the surface that is desired (BRE, 1973).

New approaches are established in contemporary wall construction concerning the changes in understanding of the building materials and their behaviour. The most important one is related to the water and vapour impermeability requirements of an exterior wall. Not so far, the tendency was to create impermeable exterior walls by using moisture-proof and vapor-proof layers in wall sections. However, any failure, such as tiny cracks, in one of these impermeable layers causes the accumulation of entrapped moisture and does not permit its evaporation from the exposed surfaces. This results in decrease in the life time of building materials, visible defects on wall surface, such as discoloration, cracks, scales and flakes on finish coats and unhealthy interiors (Bochen et al., 2005). The term “breathing walls”, therefore, gained importance in the last decades and such wall sections were constructed by using permeable layers allowing the passage of water vapour through the wall. Another development in building construction was to improve the energy efficiency in buildings by using thermal insulation layers, such as expanded polystyrene, extruded polystyrene, rockwool and glasswool insulation materials and light-weight porous masonry blocks/panels for wall sections, such as autoclaved aerated concrete. Due to their high water absorption capability, such porous masonry blocks require to be protected from rainwater by means of watertight protective coatings and/or by water repellents (Kuş, 2002). For these reasons, the production of and the demand for exterior finishing systems consisting of multi layers of base, under and

finish coats/plasters are necessary, without doubt, having low water permeability but high water vapor permeability properties.

Finish coats should also be compatible with the other neighboring materials in a wall section to execute the performance expected from them. Materials are considered to be compatible with each other if they have similar characteristics in terms of their physical and mechanical properties (Andolsun, Tavukçuoglu, Caner-Saltık and Düzgüneş, 2006; Andolsun, Tavukçuoglu and Caner-Saltık, 2005; Karoglou, Moropoulou, Krokida and Maroulis, In Press; Fassina et al, 2002; Sasse and Snethlage, 1997). Some of the most important parameters of compatibility are water vapour permeability and modulus of elasticity (E_{mod}) (Andolsun et al., 2006; Andolsun et al., 2005; Fassina et al., 2002; Sasse and Snethlage, 1997). It is essential to understand the relation between each layers of a wall and its finishing system in terms of their water and water vapor permeability, and modulus of elasticity. What is special for the finish coat is to permit the water vapor transmission while resisting to the rain water penetration, acting as a watertight material (Harderup, 1996; Cerny, Drchalova, Hoskova and Toman, 1996; Kuş, 2002). Continuity in the water vapor transmission should be provided between all layers of a wall section in order to prevent condensation problems within the wall section (İzocam, 2004; Caner, 2003; Akyazı, 1998; Akkuzugil, 1997; Sasse and Snethlage, 1997; BRE 1969). Any compatible layer should also be expected to have E_{mod} value not higher than these of the base material in touch to prevent the mechanical damage in the weaker intermediate layers and to improve the adherence

between the layers (Paulo, Veiga and Brito, In Press; Caner, 2003; Tuncoku, 2001; Fabri and Grossi 2000; Sasse and Snethlage, 1997).

The basic physical, mechanical and compatibility properties of the finish coats and their complementary sub-layers forming the overall exterior finishing systems are not known well. The compatibility of each layer building up contemporary exterior wall sections has not been assessed in detail in terms of water vapour permeability and modulus of elasticity. Some extensive and comprehensive studies are, therefore, necessary to reveal this information, to improve the system details for externally insulated wall sections and to achieve healthy interiors.

1.2 Objectives

By the end of this study, it was expected to understand whether the finish coats produced in Turkey are compatible or not with the complementary sub-layers forming the contemporary exterior finishing systems for insulated walls. Their compatibility was examined in terms of some basic material characteristics with an emphasis on water vapour permeability and modulus of elasticity properties by taking into account their adequacy, appropriateness and continuity along the wall section. By this way, it was expected to make the architects, practitioners, manufacturers, *etc*. aware of the importance of the compatibility and continuity properties for building materials by pointing out that not only their material properties, individually, are important, but also, their suitability with their neighboring materials forming a part of an overall structure, is essential.

It was also expected to achieve a reliable data on the basic physical and mechanical properties of finish coats, such as bulk density, porosity, water absorption capacity and water vapour permeability, ultrasonic velocity and modulus of elasticity.

A data on the water vapour permeability properties of some additional layers of the insulated wall sections, such as thermal insulation materials, cement-based undercoats, primer and paint, was also expected to achieve by the end of this study.

Finally, by this research, the results were intended to contribute to the improvement of contemporary finish coats and some other complementary materials, all of which forming the overall insulated wall section, in terms of physical, mechanical and compatibility properties. Thus, this research was also expected to contribute to the contemporary building materials science and building technology, in terms of the development of new materials and of some specification and evaluation methods for the finish coats.

1.3 Procedure

This study was conducted in four phases. In the first, a literature survey was done on the types and material properties of finish coats and their applications on contemporary wall sections. Some finish coats forming the exterior finishing systems of insulated masonry walls were also determined for the laboratory analyses of this study.

In the second, standard test methods specially produced for the examination and evaluation of some physical and mechanical properties of finish coats/plasters were found in the standards of The American Society for Testing Materials (*ASTM*), Deutsches Institut für Normung (*DIN*) and Türk Standartları Enstitüsü (*TSE*), and in the recent works on material analyses of building materials.

In the third, the samples were prepared from the materials selected for the laboratory analyses and then analyzed according to the standard testing methods described in the following chapter "Materials and Method".

In the final, the results obtained from the experiments were evaluated and discussed in terms of material properties with an emphasis on water vapour permeability and strength properties of the finish coats and their compatibility with other neighbouring materials used together in the insulated external walls.

1.4 Disposition

The study is presented in five chapters, of which this introduction is the first. In the second chapter, a summary of the literature related to the types and material properties of exterior finish coats and coating systems is presented together with the insulated wall sections claded with them. Compatibility and continuity properties of the finish coats and classification and standards used for their comparison are also explained in this chapter, especially with an emphasis on water vapour permeability and modulus of elasticity properties. This chapter is concluded with general

information about the importance of water permeable finish coats in wall section and of proper selection of materials forming the overall exterior finishing system for insulated walls related to the moisture problems in buildings and failures on finish coats.

In the third chapter are given the descriptions of material and wall sections examined including the sampling where the nomenclature of the samples, experimental methods for laboratory analyses of physical properties such as bulk density (ρ), porosity ($\emptyset$), water absorption capacity (θ_{max}), water vapour permeability and partial water vapour pressure distribution and mechanical properties such as ultrasonic pulsevelocity (UPV) and modulus of elasticity (E_{mod}) and the preparation of the samples were described. The methodologies used for the evaluation of data are also described in this chapter.

In the fourth chapter, results of the laboratory analyses and the calculations are presented with figures and tables.

In the fifth chapter, discussion of the results and conclusion are presented. The data is evaluated for the assessment of adequacy and compatibility of exterior finish coats applied on insulated wall sections in terms of some physical and mechanical properties. An emphasis is given to properties water vapour permeability and modulus of elasticity and results are discussed in terms of continuity of water vapour permeability and modulus of elasticity along the wall section and effect of other layers, such as primer, paint and thermal insulation boards, to the overall

water vapour permeability of wall section. This chapter ends with conclusion, where the findings of the study are summarized and recommendations are offered for future studies.

CHAPTER 2

LITERATURE SURVEY

In this chapter a survey of literature related to the exterior finish coats and coating systems is presented together with the insulated wall sections constructed with these coating systems. Compatibility and continuity properties of the finish coats are explained in terms of water vapour permeability and modulus of elasticity. General information about the role and importance of water permeable finish coats is given in relation with moisture problems in buildings. Information about the modulus of elasticity of some other exterior plasters/finish coats is also given to compare them with the ones examined in this study in terms of adequacy and compatibility.

2.1 Finish Coats

Plastering is intended to conceal the unevenness in the background and to provide a finish coat that is smooth, crack-free, hygienic and resistant to damage and can easily be decorated (BRE, 1973). Finish coats are used in the external walls to protect them from the external agents of decay as well as to obtain a homogeneous, durable, flat, and aesthetically agreeable surface (Bochen et al., 2005; Gürdal and Acun, 2004; Fassina et al., 2002; Pfeifer et al., 2001; Taylor, 1991).

Finish coats are usually factory mixed plasters that provide color and/or texture to the wall construction backing it (Williams and Williams, 1994). They are final coat of a multi-coats plastering system called as “coating system”. Each coating system is basically composed of at least two layers of “undercoat” and “finish coat”. In some cases, a layer called “primer” is applied between undercoat and finish coat in order to enhance system performance for adhesion or water resistance (Harris, 2000; Williams and Williams, 1994). The application method of these coats differs according to the type of the finish coat and wall section. These were described in the following sections.

2.1.1 Types of Coating Systems/Finish Coats

A coating system is usually classified according to its place of use on the structure or the associated conditions to which it will be subjected (Pfeifer et al., 2001). It comprises several coats, each of them in different composition to achieve different requirements.

Undercoat is the bottom coat of a multi-coat finishing system. They are usually of cement base and serves as the system’s primary waterproofing mechanism as well as the substrate for the finish coat (Williams and Williams, 1994). Depending on the coating system, it can be either a single-layer or two-layer coating. Single layer undercoats are commonly applied on externally insulated wall systems, on the thermal insulation board together with reinforcing mesh and the total thickness of this undercoat is approximately 0.8cm. They improve thermal insulated surface of

external walls they cover the reinforcing fabric, increase the strength of the insulated surface, prevent water penetration into the insulation layer and provide a smooth surface underneath the fine coat. This is why; they are also called “thermal insulation plasters” (Pfeifer et al., 2001). Two-layer undercoats are commonly applied on the exterior surface of internally insulated wall systems, on the brick masonry. These systems are composed of two layers; rough coat with a thickness of 1-2cm and fine coat with a thickness of 1 cm.

Major components of the finish coats are the “binder” and the “filler” or “aggregate”. Their composition is completed with “additives” which are used to improve some physical and mechanical properties such as water impermeability, water vapour permeability, elasticity or thermal resistance and with “pigments” which are used to provide color to the mixture. For example, silicon added elastic plasters are to be used at externally insulated external walls due to their better resistance to water penetration and elasticity (http://www.kaleterasit.com.tr, 2006; Taylor, 1991; BRE, 1973).

Finish coats are classified according to their material compositions, usually according to their binding material. According to Williams and Williams (1994), there are two types of finish coats which were formerly classified by their composition: *PB* and *PM* systems incorporated “polymer-based” or non-cementitous finish coats and “polymer modified” or cementitous finish coats, respectively. In general, there are several types of contemporary plasters or finish coats; cementitious finish coats such as cement, lime, gypsum plasters (Watson,

2000) and non cementitious finish coats such as polymer- and synthetic emulsion-based plasters.

Cementitious plasters undergo physical or chemical change during the mixing or curing process. During their curing of 28 days, they complete their shrinking process before the application of any upper coat (Taylor, 1991). Among these, binding material of cement plaster is the Portland cement, which is essentially a combination of limestone and claylike substances (Watson, 2000). Portland cement is very durable and resistant to the water permeability and capillary suction, it is preferably used in areas where dampness problems occur. Portland cement plaster is difficult to trowel. For this reason, a plasticizing agent, such as hydrated lime or certain clays is added in small quantities in order to improve the workability (Watson, 2000).

Lime plasters are classed as finishing lime according to Watson (2000). Lime is an essential component of lime plasters and obtained from limestone, marble, coral or shells which have been heated or burned in a furnace or kiln (Caner, 2003; Watson, 2000). Lime itself is a good binder but does not have enough strength, contracts on drying and develops cracks. It needs aggregates and/or some admixtures to build up an internal framework (Caner, 2003). Lime plasters are more permeable to water vapour when compared to the cement ones (Fassina et al., 2002).

Gypsum plasters were used since ancient times, which go back to Roman era. They are prepared by heating gypsum mineral or selenite rock; both are composed of

hydrated calcium sulphate. Although gypsum is very soluble in water, it can be improved by the addition of hydraulic additives such as hydraulic lime (Caner, 2003; Tuncoku, 2001).

Non cementitious finish coats are associated with lower densities, higher porosities, lower resistance to water vapour flow and better water resistance. Polymer-based finish coats are composed of polymers, which are organic compounds whose structures usually can be represented by repeated small units (Harris, 2000). Polymers are formed at the end of a process called polymerization, which occurs by reaction or combination of monomers with one another (Watson, 2000; Taylor, 1991). The polymer is called copolymer if reacted monomers are different (Taylor, 1991). Physical characteristics of the polymers are governed by the monomers and methodology used in the polymerization and the additives used during the operations. It is known that polymerization of the components or addition of polymers into the pores improves strength properties of the materials (Çolak, 2006). Synthetic emulsion-based finish coats are of synthetic resin-based, which are formed either by polymerization or condensation, or by modifying natural material (Harris, 2000).

Primer is used before polymer- or synthetic-based finish coats in order to promote its adhesion to the cement-based undercoat (http://www.kaleterasit.com.tr, 2006; Harris, 2000; Williams and Williams, 1994). Thus, while non-cementitous finish coat system is composed of three layers of cement-based undercoat, primer and finish coat, a cementitous finish coat system is composed of two layers of cement-

based undercoat and finish coat. In addition, the finish coat should be painted in cases when a colorless final coat such as cementitious finish coat was selected.

In recent times, although non cementitious external finishes has gained favor due to their better physical and mechanical performances, especially resistance to water penetration and permeability to water vapour, in fact, they are not well known yet. In this study, some cementitious and non-cementitious finish coats were analyzed and compared with each other in terms of their basic physical and mechanical properties.

The finish coats examined in the study were the products of a Turkish firm engaged in producing some plasters, coatings, mortars, paints and chemical additives. They were found in the market for ready-use, either in liquid or powder state. According to the brochures published by the firm and information directly taken from the specialists of the firm their finish coats were classified basically in four categories of synthetic emulsion-based (*SB*), cement-based (*CB*), acrylic polymer-based (*APB*) and acrylic copolymer-based (*ACB*). It was observed that while some finish coats and coatings have similar characteristics, some of them differ excessively. The samples were selected from all categories by taking into account of these differences or similarities. These finish coats were described in detail in the following chapter "3. Materials and Method".

Not much data on the material properties of finish coats are available. Even no data was found on their water vapour permeability and modulus of elasticity properties.

In addition, a very restricted data about this type of contemporary finish coats were found. One of these is some requirement defined in the standards about finish coats which were described in following section "2.2 Compatibility and Continuity Properties of Materials".

2.1.2 Wall Sections

Compatibility of finish coats with the other building materials forming an overall insulated exterior wall section was examined in the study. Some of these walls, therefore were described below including their types and materials.

External walls have major structural and physical functions to perform, such as thermal and sound insulation, fire protection and protection against driving rain (Pfeifer et al., 2001). In addition, special requirements may need to be fulfilled such as being load bearing walls and/or water proofing against pressurized or non-pressurized water. Basically, thermal requirements are decisive factors since the type and positioning of thermal insulation layer define the characteristics of an insulated external wall.

Due to the climatic condition of Turkey, thermal insulation in buildings is essential for external walls and construction and are defined clearly by Building Regulations (2003) and Standards (TSE, 1998). There are several insulated external wall sections which can be classified in five groups according to the position of the thermal insulation board. These are externally insulated, internally insulated,

sandwich, ventilated and cavity walls, shown in sketches in Figure2.1.Among these, externally insulated, internally insulated and ventilated walls are called “single leaf walls” and the sandwich and cavity walls are called “twin leaf walls” (Pfeifer et al., 2001). In twin leaf masonry systems, the inner leaf provides a solid enclosure to the interior and carries the vertical and horizontal loads. The outer leaf determines the visual appearance and serves as protection against the weather and mechanical damage.

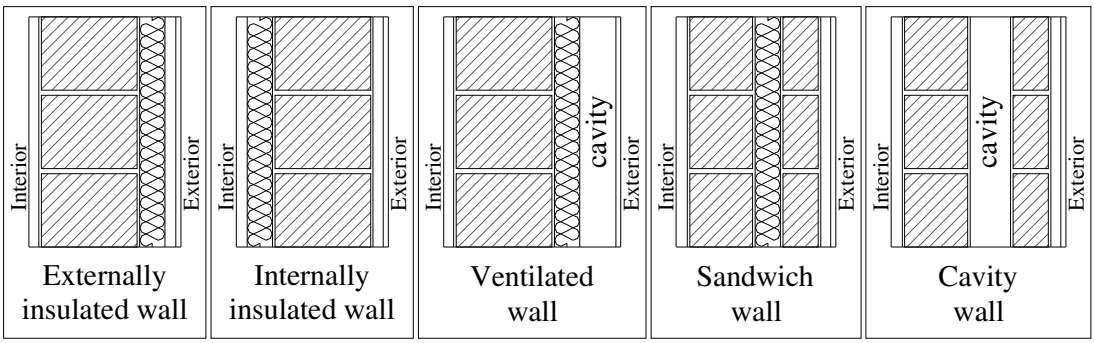


Figure 2.1 Types of external wall (http://www.izocam.com.tr, 2006).

In externally insulated single leaf masonry wall, the thermal insulation material is installed on the exterior surface of masonry wall. Two methods were used to stick the insulation board. One of them is “notched trowel method”, where a continuous layer of adhesive is applied over the overall backing surface of the thermal insulation board, as shown in Figure 2.2.a. the second one is “ribbon and dab method”, where a ribbon of adhesive is applied over the periphery of its backing surface and supported by means of dabs applied in spots on the backing surface, as shown in Figure 2.2.b. (Williams and Williams, 1994). Following the application of adhesive, the board is fixed on the wall by mechanical fasteners. In this type of

walls, the board surface is plastered with reinforced thermal insulation undercoats in order to provide a smooth subsurface for the application of final coat and also to protect the insulation board from moisture penetration (Figure 2.3.). The reinforcement of the undercoat is provided by reinforcing mesh which improves mechanical strength of the coating. Over this layer, either cementitious or non-cementitious finishing system is applied.

Figure 2.2.a. Application of bedding plaster to thermal insulation board by notched trowel method (www.bulak.net, 2006)

Figure 2.2.b. Application of bedding plaster to thermal insulation board by ribbon and dab method (www.bulak.net, 2006)

Figure 2.3. Application of thermal insulation undercoats with reinforcing mesh (www.bulak.net, 2006)

In internally insulated walls, the thermal insulation board is fixed on the interior surface of the external wall by means of application methods explained above. The insulation board is generally plastered with a cement lime-based plaster or covered with gypsum board. The external surface of the masonry wall is commonly plastered with cement-based rough and fine undercoats before the application of the finish coats.

Ventilated walls are similar to the externally insulated wall with an exception of a cavity left between the exterior finishing system and the thermal insulation layer. This cavity is provided by means of dry wall construction and the exterior finish system is directly applied on dry wall surface. It can also be either a curtain wall or pre-cast cladding material.

The thermal insulation material is placed in between two leaves of the exterior wall in sandwich walls while an air gap, which has a sufficient thermal resistance, is left between these two leaves of cavity walls. The interior and exterior surfaces of the

masonry are commonly plastered with plasters/finish coats as mentioned above paragraphs.

In Turkey, among all of these wall sections, two of them, externally and internally insulated walls are commonly applied ones in construction, especially due to the climatic and economic reasons. The contemporary exterior finish coats applied on these wall sections were, therefore, examined in this study. Explanation and detailed information about these two wall sections were given in detail in the chapter "3.Materials and Method".

2.2 Compatibility and Continuity Properties of Materials

In recent time more attention was given to the durability problems of building materials and components. The key issue is to define the service life of the building (Bochen et al., 2005). External finishes protect external walls from the destructive effects of weathering agents such as temperature changes, moisture, solar radiation, wind and atmospheric gasses. Due to such weathering conditions, finish coats deteriorate and lead to changes in their physical, mechanical and chemical properties. Decay form, such as discoloration, scales, flakes and/or cracks, are observed in a short period of time after the application of finish coats. This may be owing to improper selections of finish coats having physical and mechanical properties not similar to the other neighbouring materials of the background.

According to Williams and Williams (1994), the durability of a material is related with its compatibility with all other building materials with which they come in contact. In fact, there are several physical, mechanical and chemical properties affecting the durability of the materials and health of the construction and thus inhabitants. Compatibility of a material can be defined as its suitability with other building materials used together in terms of some material properties which should be similar with each other in order to prevent any failure of the assembly (Andolsun et al., 2006; Karoglou, In Press; Paulo et al., In Press; Caner, 2003; Tuncoku, 2001; Fabbri and Grossi, 2000; Sasse and Sneathlage, 1997; Williams and Williams, 1994). In this study, an emphasis was given on the compatibility and continuity of water vapour permeability and modulus of elasticity properties of exterior finish coats in a wall section since most failures are due to the moisture problems and mechanical failure.

2.2.1 Water Vapour Permeability Properties

Water vapour permeability of a material can be briefly described as its "breathing" property. In other words, a water vapour permeable material lets easily the passage of water vapour through its body (Caner, 2003). There are some parameters related to water vapour permeability, such as water vapour transmission rate (R_T), permeance, equivalent air layer thickness of water vapour diffusion (S_D), permeability (S_D^{-1}) and water vapour diffusion resistance index (μ).

The parameters, finish coats/plasters were described in the standards of The American Society for Testing Materials (ASTM), Deutsches Institut für Normung (DIN) and Türk Standartları Enstitüsü (TSE) and in other publications (Strother and Turner, 1990; Teutonico, 1986; RILEM, 1980; BRE, 1969) together with the experimental procedures and calculation methods for the determination of these parameters. All were explained in detail in the following chapter "3. Materials and Method".

Water vapour transmission rate R_T (g/hm^2) and permeance (g/Pasm^2) defined in the standards determine water vapour flux through (Richardson, 2001; TSE 1999; ASTM, 1992; Strother and Turner, 1990; DIN, 1987). Tye (1994) states that published data for the permeability and permeance properties show that there are very broad ranges of values for different materials. Different experimental procedures and calculation methods were also available in literature for determination of R_T and permeance of a plaster/finish coat (Pfeifer et al., 2001; TSE, 1999; ASTM, 1992; DIN, 1987).

Equivalent air layer thickness of water vapour diffusion, S_D on the other hand, is inversely proportional with R_T and permeance values and expressed as the thickness of the motionless air in meters (m) which has the same vapour resistance on the material with a certain thickness, "*d*" (TSE, 1999; TSE, 1990; DIN, 1987). Water vapour diffusion resistance index, μ indicates the resistance of a material to the water vapour transmission. It is a unitless parameter and used to compare the materials regardless of their thicknesses (TSE, 1990; DIN, 1987). S_D value for each

layer can be calculated by multiplying μ value with the thickness of the layer. A material with high μ may have considerably low S_D value when they are applied in thin layers and more permeable layers can be achieved with a conscious application of layer thickness (Esen, Tunç, Telatar, Tavukçuoğlu, Caner-Saltık and Demirci, 2004; Akyazı, 1998; Akkuzugil, 1997). Permeability is another term which is calculated by the inverse of S_D value and expressed in m^{-1} (TSE, 1999). A higher S_D value the material has, a lower permeable it is.

The numerical data for S_D and R_T values and the classification for permeability properties given in different standards were collected in Table 2.1. In order to summarize the ranges for low, medium and high water vapour permeable exterior finish coats/plasters.

Table 2.1. Classification of water vapour permeability properties for finish coats/plasters in terms of S_D and R_T values.

Building Material	Low Permeable	Medium Permeable	High Permeable	Source of data
Finish coat	S_D<2m is acceptible			TS 7847, 1990
General	S_D >1.4m	0.14m< S_D <1.4m	S_D <0.14m	TS prEN ISO 7783-2,1999
General	R_T<0.6g/m^{2}h	0.6g/m^{2}h<R_T<6g/m^{2}h	R_T>6g/m^{2}h	TS prEN ISO 7783-2,1999

In this regard, there are some researches on the water vapour permeability properties of contemporary building materials (Andolsun et al., 2006; Kuş, 2002; Pfeifer et al., 2001; TSE, 1998; Hedenblad, 1996; Tye, 1994; Williams and Williams, 1994; Strother and Turner, 1990) and historical building materials (Esen et al., 2004; Caner, 2003; Cerulli, Pistolesi, Maltese and Salvioni, 2003; Akkuzugil, 1997).

Pfeifer (2001) prepared a list of μ values used for calculating the quantity of condensation for some building materials by referring to DIN 4108 part 4. μ values recommended for these calculations were given in the range of 15 and 35 for lime, lime-cement and hydraulic lime plasters, 10 for gypsum plasters, in the range of 50 and 200 for synthetic resin plasters, in the range of 5 and 20 for thermal insulation plaster and in the range of 50 and 200 for synthetic resin plaster. The range of μ values for the masonry of autoclaved aerated concrete, AAC and clay bricks were also given from 5 to 10.

According to the studies of Strother and Turner (1990), permeability values of foamed polystyrene and mineral wool were found to be in the range between 0.3 to 0.9 perms and 30.0 to 75.0 perms, respectively. The permeability for the brick was also given to be 5.0 perms and 54.0 perms for gypsum plaster.

One of the works was done by Tye (1994), who collected permeance values of some contemporary building materials in a list from some major sources such as ASHRAE Handbook (1989), Computerized Material Moisture Property Data Base developed by the Florida Solar Energy Center (Kerestecioğlu, 1988) and from some authors; Tveit (1966), Pragnell (1971) and Burch, Thomas and Fanney (1992). The permeance values for exterior acrylic paint, primer and plaster were given as 0.31×10^{-6} g/Pasm^2, 0.36×10^{-6} g/Pasm^2 and 1.14×10^{-6} g/Pasm^2, respectively, in this list.

In another work, Williams & Williams (1994) summarized the water vapour transmission performance test requirements for cementitious finish coats by referring to American Institute of Architects (1993). The maximum permeance value for an exterior finishing system of an externally insulated wall consisting of cement-based finish coat, primer and undercoat together with reinforcing fabric was given as 7.5 perms ($4.3x10^{-7}$g/Pasm^2) and for a 2.54 cm thick polystyrene insulation board, this value was given as 1 perm ($0.57x10^{-7}$g/Pasm^2) in maximum.

Hedenblad (1996) studied on experimental methods to determine water vapour permeability properties of 25 different contemporary building materials. He concluded that the experimental results were affected directly from the varying boundary conditions of the experimental set-up such as temperature and relative humidity.

Cerulli et al. (2003) made a research on several types of plasters in order to analyze their durability in terms of their physical, mechanical and chemical properties. He calculated μ values of some plasters ranging from 8 to 21 and concluded that long term durability for plasters depended upon low water permeability and high water vapour permeability properties.

Andolsun et al. (2006) has worked on the compatibility properties of some plasters specially produced for autoclaved aerated concrete masonry. She found that the S_D and μ values of an AAC masonry wall of 20 cm thickness were 0.87m and 4.4m, respectively. Experimental μ values of the base coat, undercoat, finish coat and

water repellent finish coat were given as 11.5, 1.4, 11.5 and 5.8, respectively. Some recent studies also exist on the physical, mechanical and durability properties of water repellents applied on AAC masonry (Kuş, 2002).

Historical plasters were also investigated in terms of their water vapour characteristics. The physical and mechanical properties of some historic interior and exterior plasters belonging to Seljuk period were analyzed by Caner (2003). In her study, the necessity of water vapour permeable layers on the outer periphery of the buildings was pointed out and S_D and μ values for exterior historic plasters were found to be in the range of 0.031m to 0.049m and of 2.31 to 4.65, respectively. As a conclusion, she stated that the plasters were found to have good breathing properties and continuity of the water vapour flux was provided through the plaster layers.

Another research was conducted on the examination of some historical plasters of timber framed historical buildings in Ankara in terms of S_D, μ and permeance values (Akkuzugil, 1997). In this work, lime plasters were found to have relatively higher μ values than mud and gypsum plasters. The μ values of the historic lime, mud and gypsum plasters studied by her were found to range from 3.04 to 18.27, 1.19 to 3.16 and 2.88 to 13.33, respectively. S_D values of the lime plasters were found to range from 0.026m to 0.059m, indicating that these plasters were high vapour permeable materials. It was pointed out that even some of the layers had higher resistance to water vapour permeation; a continuous passage of water vapour through all plaster layers was achieved by the conscious application of different thicknesses.

In another research (Esen et al., 2006), the plasters of a 14th century Turkish Bath were found to be very permeable with S_D values ranging from 0.04m to 0.15m and μ values from 2.3 to 16.2. In interiors up to a level of 1.50 m where the wall surfaces directly exposed to water, plasters with higher μ values were found to be used in thinner layers and similar permeability were achieved along the plaster layers. All studies have shown that in historical buildings there was a very conscious use of plaster technology according to the function of the spaces in terms of material production, selection and application.

2.2.2 Modulus of Elasticity

The modulus of elasticity (E_{mod}) is defined as the ratio of stress to strain and indicates the deformation ability of a material under external forces (Timoshenko 1970). The assessment of a layer whether it is compatible or not with its sub-layers in terms of its E_{mod} values, is still a question under discussion and the healthy relationships between the coating layer in terms of their E_{mod} values and their strength are not exactly defined yet. According to the studies discussing this subject, it was stated that in multi layer systems, E_{mod} value of the coating materials should not exceed that of the masonry (Paulo et al., In Press; Caner, 2003; Tuncoku, 2001; Fabbri and Grossi, 2000; Sasse and Sneathlage, 1997). In other words, the elasticity of the layers should lower through exterior, but still by keeping enough strength, by means of which a smooth transition zone between the substrate and coating is achieved (Sasse and Sneathlage, 1997). Otherwise, failures, especially in the form

of tiny cracks are commonly observed on the fine coat and/or sub-layers followed by flakes and scales.

E_{mod} values for rock can be determined by means of some equations using *UPV* measurements and bulk density of the material that were defined in the standards of RILEM (1980) and ASTM (1990). Any standard test method for the analysis of contemporary finish coats, however, could not be found in the literature. On the other hand, several studies were done on some types of historic materials such as rock, brick, mortar, plaster and timber by using the testing method defined in these standards (Esen et al., 2004; Caner, 2003; Tuncoku, 2001; Tuncoku, Caner-Saltık and Böke, 1993).

Tuncoku (2001) worked on some brick and stone masonry mortars of Anatolian Seljuk monuments in Konya, Beyşehir and Akşehir. In his study, it was expressed that the E_{mod} values of brick and stone masonry mortars were in the approximate range from 0.71GPa to 2.99GPa and from 0.72GPa to 2.38GPa. So, they had similar physical mechanical and durability properties with the masonry forming a monolithic brick or stone structure.

Caner (2003) investigated some plasters of Seljuk period. E_{mod} values of these plasters were found to be in the range of 1.5GPa and 3.3GPa. All plasters were found to have enough mechanical strength comparable to some historical bricks and mortars. Esen et al. (2004) studied the interior plasters of a 14^{th} century bath building and found E_{mod} values of these plasters as in the range of 1.04GPa and

2.91GPa. In the study, it was stated that E_{mod} value of the plasters should be high enough to survive for hundreds of years, while not exceeding the E_{mod} values of stone and brick masonry backing it.

There are also some researches on E_{mod} values for contemporary plasters using UPV values for the calculation of E_{mod}. For instance, Çolak (2006) has worked on some calculation methods for the E_{mod} values of the finish coats and compared the data obtained from the calculations with the results of the experiments done according to the standards of *ASTM* (1990). He concluded that the experimental and calculated results were close to each other. He also found that the E_{mod} values of some polymer-based finish coats were ranging from 4.0GPa to 8.6GPa. Another study on contemporary cement-based exterior plasters, specially produced for Autoclaved Aerated Concrete, AAC, was done by Andolsun et al. (2006) who have found that E_{mod} values of the base coat, undercoat, rendering and water repellent finish coat were found to be 4GPa, 3.6GPa and 4.3GPa, respectively while E_{mod} value of a load bearing AAC unit was lower such as 2.1GPa.

2.3 Importance of Water Vapour Permeable Finish Coats

In the 19th century construction technology, the general tendency was to build up exterior walls with an impermeable layer to moisture at the exterior side against rainwater penetration and with a vapour barrier at the interior side against moisture absorption and condensation. However, due to any failure at these impermeable layers, such as tiny cracks, moisture penetrates into and then is entrapped in

the wall section and this resulted in considerable moisture problems in buildings. Such problems shorten the service life of the materials and construction and cause unhealthy living conditions in buildings. In contemporary construction, this tendency, therefore, changed to the buildings with “breathing walls”, all layers of which consisted of permeable materials.

As mentioned in BRE (1969), if the outer portion of the wall is permeable to moisture, or if ventilation is provided behind an impermeable wall or roof cladding, condensation is not troublesome because water vapour can evaporate gradually to the outside air. In contrary, if the finish coat is impermeable to water vapour, in other words, not permit wall to evaporate, any moisture within the wall section will tend to accumulate in the wall and accelerate the problems sourced from moisture (Cerulli et al., 2003; Richardson, 2001). In this respect exterior finish coats forming the exterior finishing system are expected to be water vapour permeable materials in order to let the passage of the water vapour in the wall section, while resisting to the rain water penetration, acting as a watertight material (Kuş, 2002; Cerny et al., 1999; Harderup, 1996).

The moisture content and water vapour pressure inside an occupied building is usually higher than outside. The water vapour then will tend to move by diffusion, towards outside (İzocam, 2004; Pfeifer et al., 2001; Richardson, 2001; Everett, 1994; Williams and Williams, 1994; BRE, 1992; Strother and Turner, 1990; BRE, 1969). The water vapour diffusion in a wall section depends on the water vapour permeability characteristics of each material/layer and should be continuous along

the wall section, in order to prevent condensation within or between its components. In other words, not only the finishing system, but also the layers underneath should be vapour permeable in order to prevent any accumulation of moisture in the wall section and let it transmit to the exposed surface. It is, therefore, necessary to understand the relation between each layers of a wall in terms of their water and water vapor permeability, continuity of water vapour transmission between the layers and the adequacy of this vapour flux.

2.3.1 Condensation Problem in Buildings

Moisture is one of the major problems in buildings mainly sourced from rain penetration, rising damp, condensation and leakages in the piping system of the building. It is well known that moisture causes decay of building materials. If moisture sources are not taken away from the building or excessive humidity in the wall does not come out of the wall by moisture transportation, it will cause several problems which will end up with the deterioration of the materials (Karoglou et al., In Press; Caner, 2003; Kuş, 2002; Toydemir, Gürdal and Tanaçan, 2000; Hedenblad, 1996; Tye, 1994; Szczerba and Jedrzejewska, 1988).

Water vapour is a gas which has a pressure in the air. The ratio of the vapour pressure to the vapour pressure of a saturated mixture at the same temperature is the relative humidity, *RH*, which is expressed in percentage (%) (İzocam, 2004; BRE, 1969). In other words, relative humidity is the amount of water vapour in the air expressed as a percentage of the amount that would saturate it at the same

temperature. The amount of water vapour that air can contain is limited and when this limit is reached the air is said to be saturated. This means that RH reaches to 100%, and the water vapour will liquefy and be deposited as condensation.

Condensation of water vapour can be either on the surface of a building element, which is called surface condensation or within the structural elements, which is called interstitial or concealed condensation (BRE, 1969; BRE, 1992). Interstitial condensation has less impact on the occupants than the surface condensation but can cause much more serious problems in long term, possibly affecting the structural integrity of the building (BRE, 1992). In addition, moisture in materials increases their thermal conductivity coefficient which is especially considered for thermal insulation materials (Kuş, 2002; Richardson, 2001; Langlais, Silberstein and Sandberg, 1994; Williams and Williams, 1994; Strother and Turner, 1990; BRE, 1969).

Cerny et al. (1999) studied on the methods for evaluating water-proofness quality of some coating materials and addressed the importance of the water vapour permeable and watertight finish coats in order to prevent the risk of condensation.

CHAPTER 3

MATERIALS AND METHOD

The materials and method are given in three sections; sampling, analyses of physical properties and analyses of mechanical properties.

In order to discuss the compatibility properties of the external finish coats in an exterior wall section, some basic physical and mechanical properties of them were examined by laboratory analyses. The samples were prepared according to the standards (TSE 2000a, 2000b; ASTM, 1992; ASTM, 1990; TSE, 1990; DIN, 1973). Some basic physical properties, such as bulk density (ρ), porosity ($\emptyset$), water absorption capacity (θ_{max}), water vapour permeability and partial water vapour pressure distribution (TSE 2000a; TSE, 1998; ASTM, 1992; Strother and Turner, 1990; TSE, 1990; TSE, 1987; Teutonico, 1986; RILEM, 1980; BRE, 1969) and some basic mechanical properties, such as ultrasonic pulse velocity (*UPV*) and modulus of elasticity (E_{mod}) (ASTM, 1990; RILEM 1980) were determined. In addition to the finish coats, some other layers, such as undercoats, primer, thermal insulation materials and paint, complementing the exterior wall section were also examined in terms of their water vapour permeability properties. For the masonry of brick and autoclaved aerated concrete (AAC) masonry blocks and for the interior finishing materials, such as gypsum board and cement-lime plaster, the data

required for the comparisons and calculations were taken from the literature (Andolsun et al., 2006; İzocam, 2004; TSE, 1998).

3.1 Sampling

In the study, four types of synthetic emulsion-based finish coats (*FC1SB, FC2SB, FC3SB* and *FC4SB*), two of which containing silicone additives, one type of cement-based finish coat (*FC5CB*), one type of acrylic polymer-based elastic finish coat (*FC6APB*) containing silicone additives, two types of acrylic copolymer-based finish coats (*FC7ACB* and *FC8ACB*), one of them containing silicone additives were analyzed. From these, all finish coats were self-colored except the finish coat *FC5CB*. Undercoats such as cement-based rough plaster ($UC1CB_R$), cement-based fine plaster($UC2CB_F$) and thermal insulation plaster ($UC3CB_T$), one synthetic emulsion-based primer (*Pr1SB*), thermal insulation materials such as extruded polystyrene (*Ti1XPS*), expanded polystyrene (*Ti2EPS*) and mineral rockwool (*Ti3RW*) boards and acrylic copolymer-based exterior paint (*Pa1ACB*) were also examined. The list of all samples examined by laboratory analyses in this study and their description were given in Table 3.1.

All finish coats, thermal insulation plaster, primer, thermal insulation materials and paint were provided from manufacturer and rough and fine plasters were prepared in the laboratory. The trade mark and names corresponding to these samples were also listed in the Appendix C. Three samples were produced for the analyses of each material and mean values were taken to prepare the data.

Table 3.1 Sample codes, state and description of the sample examined by laboratory analyses in this study.

No	Sample Code	State of Material	Description
1	FC1SB	Liquid	Synthetic emulsion-based elastic finish coat with silicone additives
2	FC2SB	Liquid	Synthetic emulsion-based elastic finish coat with silicone additives
3	FC3SB	Liquid	Synthetic emulsion-based finish coat
4	FC4SB	Liquid	Synthetic emulsion-based finish coat
5	FC5CB	Powder	Cement-based finish coat
6	FC6APB	Liquid	Acrylic polymer-based elastic finish coat containing silicone additives
7	FC7ACB	Liquid	Acrylic copolymer-based finish coat with silicone additives
8	FC8ACB	Liquid	Acrylic copolymer-based finish coat
9	$UC1CB_R$	Mixture	Cement-based rough plaster
10	$UC2CB_F$	Mixture	Cement-based fine plaster
11	$UC3CB_{Ti}$	Powder	Cement-based thermal insulation plaster
12	Pr1SB	Liquid	Synthetic emulsion-based primer
13	Ti1XPS	Board	Extruded polystyrene
14	Ti2EPS	Board	Expanded polystyrene
15	Ti3RW	Board	Rockwool
16	Pa1ACB	Liquid	Acrylic copolymer-based exterior paint

3.1.1 Nomenclature

All samples related with this study were classified according to their function in the wall system. Each sample was coded then according to their material composition. The coding method was as follows:

Classification according to the function of the sample in a wall section.

FC: **F**inish **c**oat

UC: **U**nder**c**oat

Pr: **Pr**imer

Ti: **T**hermal **I**nsulation Material

Ma: **Ma**sonry

Pa: **Pa**int

Pl: **Pl**aster

Classification according to the material composition of the sample.

SB: **S**ynthetic Emulsion-**b**ased

CB: **C**ement-**b**ased

APB: **A**crylic **P**olymer-**b**ased

ACB: **A**crylic **C**opolymer-**b**ased

T: **T**hermal Insulation Plaster

XPS: **Ex**truded **P**oly**s**tyrene

EPS: **E**xpanded **P**oly**s**tyrene

RW: **R**ock**w**ool

BM: **B**rick **M**asonry

AAC: **A**utoclaved **A**erated **C**oncrete

CLB: **C**ement-**L**ime **b**ased

The sample number was introduced between function and material composition of the samples. As an example, the explanation of the nomenclature for the sample *FC1SB* was given in Figure 3.1.

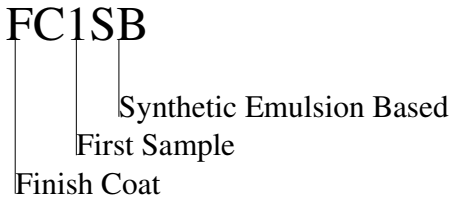


Figure 3.1 Explanation of nomenclature for the sample *FC1SB*.

3.1.2 Wall Sections Studied

Mainly two types of single leaf exterior wall sections, one externally the other internally insulated, were examined. The walls themselves were assumed to consist of masonry units, such as brick and AAC, thermal insulation boards, such as expanded or extruded polystyrene and rockwool boards; and external finishing systems, all of which have been defined in the section above together with their codes. Three alternatives for each wall section were produced by the application of different exterior finishing compositions, shown in Figure 3.2 for externally insulated and in Figure 3.3 for internally insulated wall sections.

In these sections, the thicknesses of each layer was determined according to requirements described in TSE 825, "Regulations for Thermal Insulation in Buildings", such as 19 cm for brick masonry, 20 cm for AAC masonry and 5 cm for thermal insulation board (TSE, 1998).

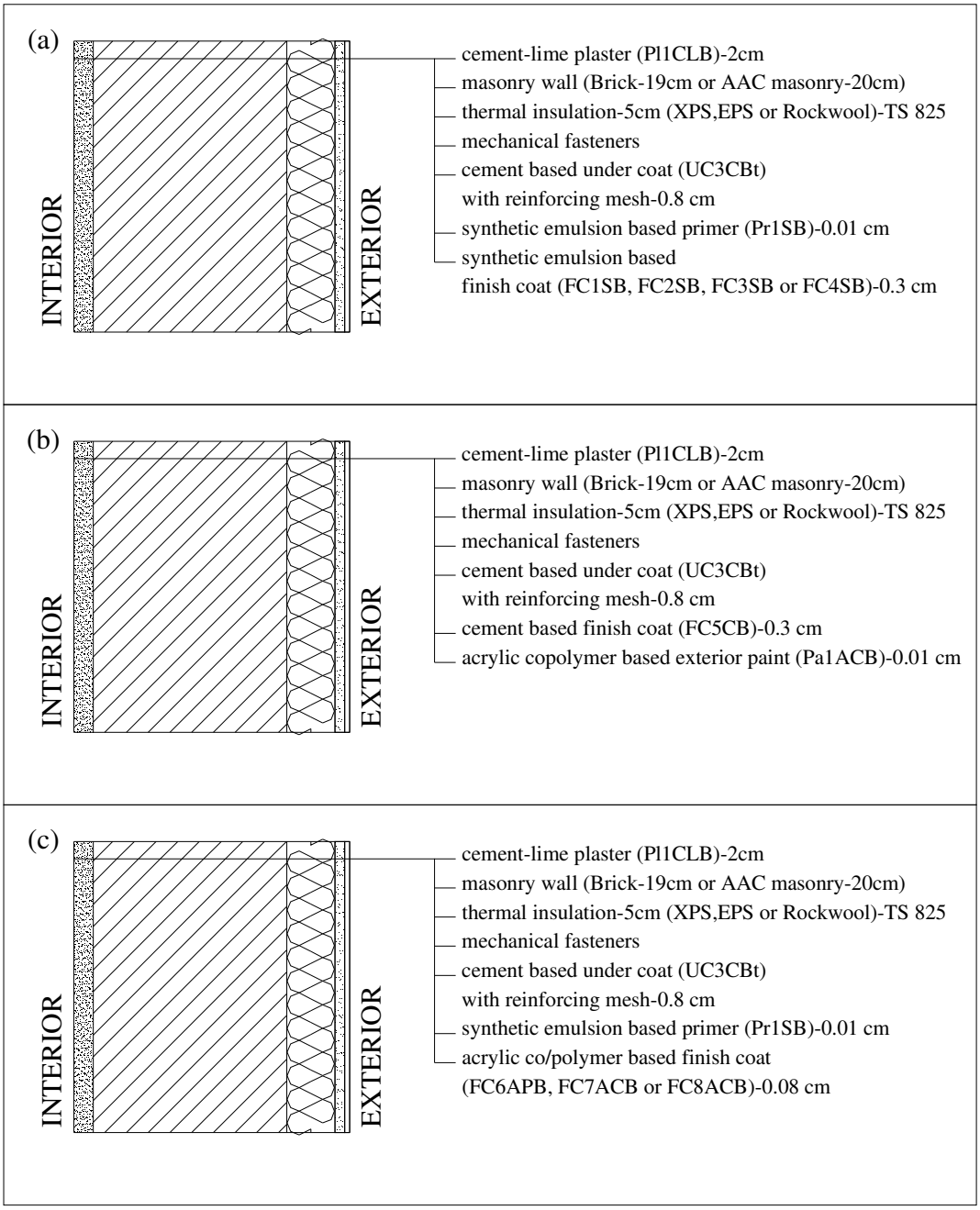


Figure 3.2. Externally insulated single leaf wall plastered with (a) synthetic emulsion-based exterior finish coat (*FC1SB*, *FC2SB*, *FC3SB* or *FC4SB*); (b) cement-based exterior finish coat (*FC5CB*); (c) acrylic polymer-based exterior finish coats (*FC6APB*, *FC7ACB* or *FC8ACB*) (http://www.kaleterasit.com.tr, 2006).

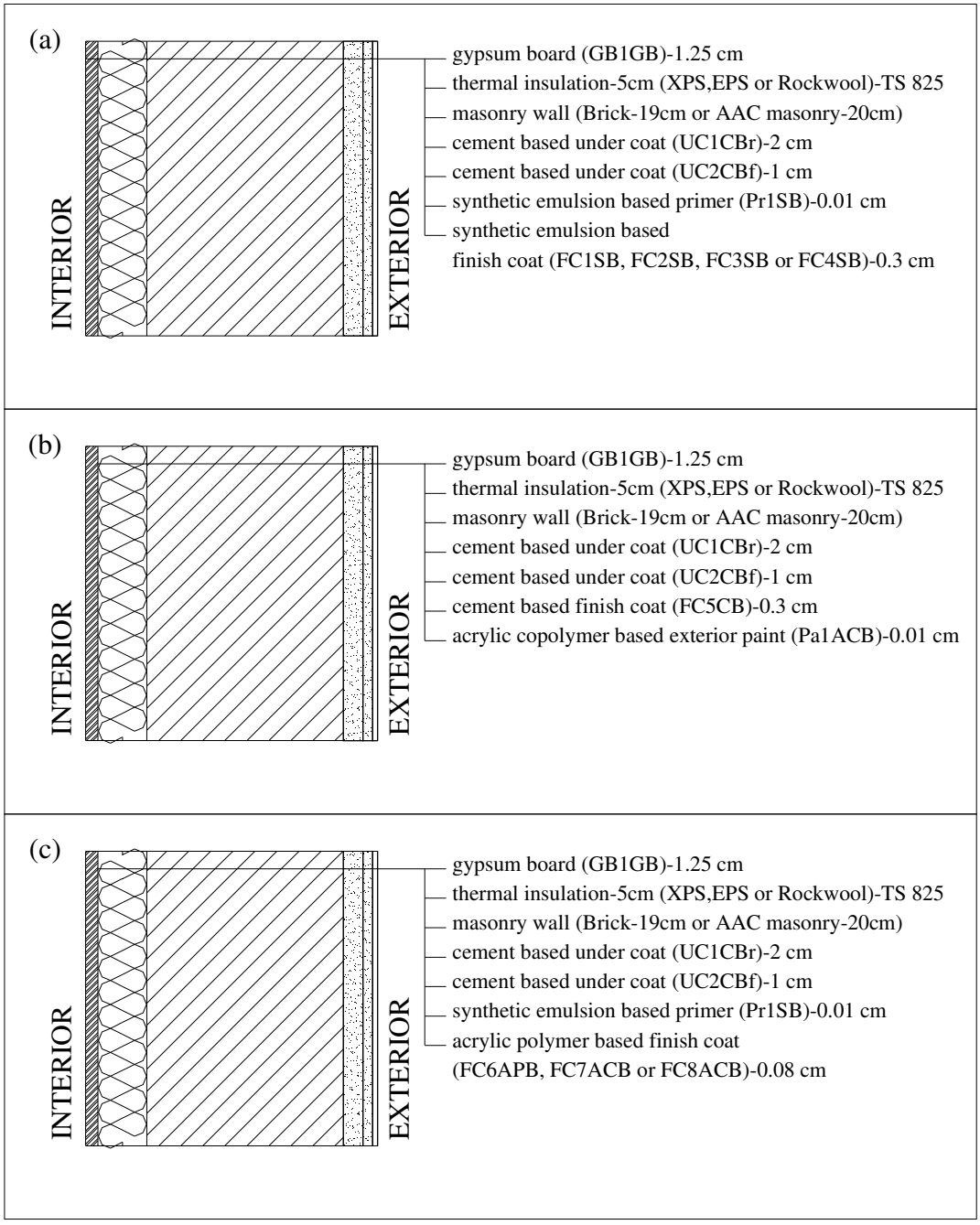


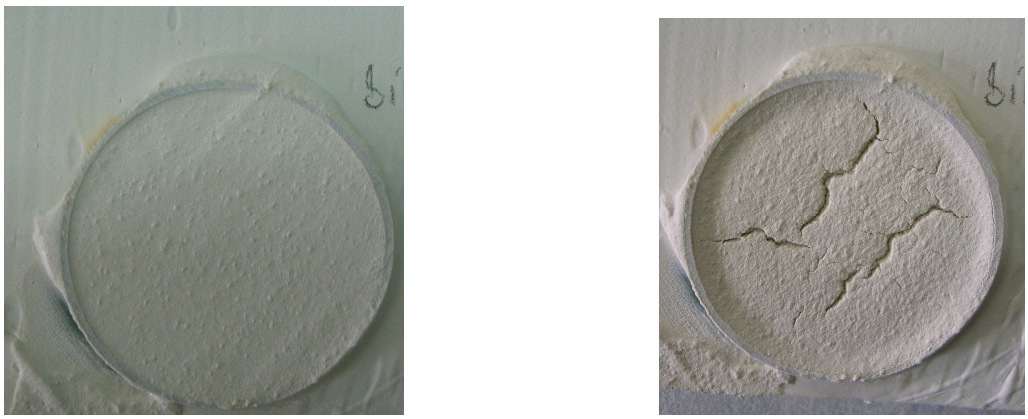
Figure 3.3. Internally insulated single leaf wall plastered with (a) synthetic emulsion-based exterior finish coat (*FC1SB*, *FC2SB*, *FC3SB* or *FC4SB*); (b) cement-based exterior finish coat (*FC5CB*); (c) acrylic polymer-based exterior finish coat (*FC6APB*, *FC7ACB* or *FC8ACB*) (http://www.kaleterasit.com.tr, 2006).

3.1.3 Preparation of Samples

For the analyses of physical properties of bulk density, porosity, water absorption capacity and water vapour permeability, samples of finish coats were prepared by using different methods due to their being in different states. All finish coats were examined individually while some of them were also analyzed together with primer or paint layer where necessary.

Samples were prepared from the finish coats in liquid form according to the TSE, TS EN 1015-2 (2000b). Samples from the finish coats found in the market in powder state were prepared according to the instructions given by the firm (http://www.kaleterasit.com.tr, 2006).

All samples were poured into the 3mm height plastic molds. During curing process of 28 days samples of acrylic polymer- and copolymer-based finish coats shrinked with cracks at the end of 3rd day (Figure 3.4). In order to prevent this failure, they are applied on some backing materials for the analyses of water vapour permeability and were kept in an ERASMUS oven at 35°C for the analyses of other physical properties, according to the recommendations given by the firm.



(a) (b)

Figure 3.4 Samples of acrylic polymer-based finish coats (a) at the beginning of the cure and (b) at the 3rd day of the cure.

Some sample sets were specifically produced for the analyses of water vapour permeability. Two sets of synthetic emulsion-based finish coats (*FCSB*) were prepared, with primer with a thickness of 0.1mm and without primer (Figure 3.5). Two sets of cement-based finish coats (*FC5CB*) were also produced with and without paint layer. The painting was applied with 10cm width Marchall Paint Roller and its thickness was measured which was about 0.1 mm (Figure 3.6). Sample of acrylic polymer-based finish coat (*FC6APB*) were prepared with two different backing materials, one on filter paper (TSE, 1999) and the other one on primer (Figure 3.7). Acrylic copolymer-based finish coats (*FCACB*) were applied on filter paper (TSE, 1999) with the same type of Marchall paint roller in two sets, with and without primer. Primer and paint layers were also examined individually. Samples of synthetic emulsion-based primer (*Pr1SB*) were applied directly on filter paper by means of the same paint roller and samples of acrylic copolymer-based paint was prepared similar to the finish coats by pouring them into the 0.3 cm height plastic molds.

Figure 3.5 Samples of synthetic emulsion-based finish coats, *FC1SB*, with (at top) and without (at bottom) primer.

Figure 3.6 Samples of cement-based finish coat, *FC5CB*, after painting.

Figure 3.7 Sample of acrylic polymer-based finish coat, *FC6APB*, applied on primer.

Since the composition of undercoats was different, samples were produced in a different way. Cement-based rough plaster $UC1CB_R$ was composed of 750 g sand (0.3mm grade), 250g cement and 6 g factory mortar and was mixed with 110 ml water. This mixture was poured in 3.5x3.5x3.5 cm cubic timber molds. Cement-based fine plaster ($UC2CB_F$) was composed of 750 g sand in fine grains, 250 g cement and 6 g factory mortar, and was mixed with 200 ml water. This mixture was also poured into the same timber molds. Cement-based thermal insulation undercoat ($UCCB_T$) was in powder state. The mixture was prepared by adding five amounts of powder to one amount of water by weight and poured into the 0.3cm height plastic molds.

All finish coats and undercoats were cured in a controlled chamber (Figure 3.8) at the boundary conditions of 20°C $\pm$2°C and 50% $\pm$5 % relative humidity (RH) for 28 days (TSE, 2000a; TSE, 1990). Constant condition of 50% *RH* was provided by saturated $CaCl_2$ aqueous solution placed at the base of the chamber (TSE, 2000a; TSE, 1990; DIN, 1973). Samples of polystyrene- and mineral-wool-based thermal insulation materials, *Ti1XPS, Ti2EPS* and *Ti3RW* were cut from the boards.

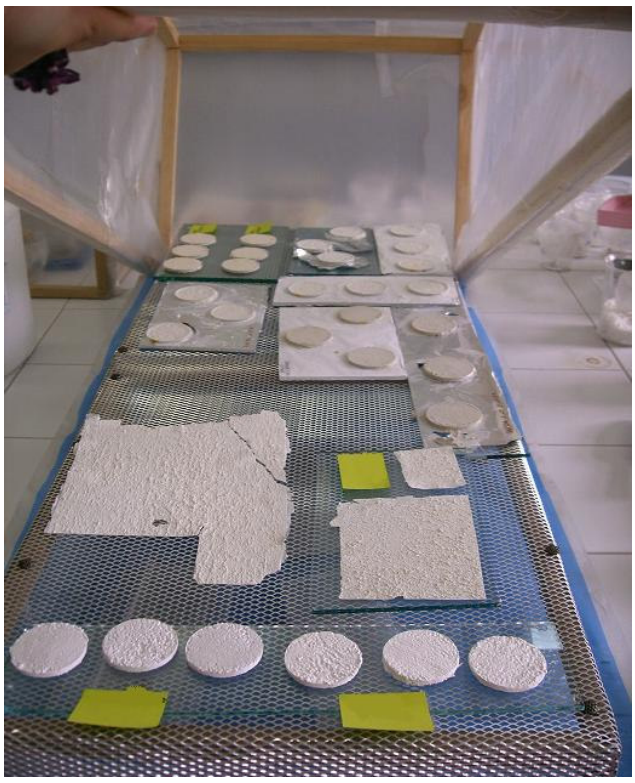


Figure 3.8 View from the interior of controlled chamber.

For the investigation of mechanical properties, all finish coats were poured in cardboard cylinders with a diameter of 4 cm and maximum height of 2.2 cm and left in oven (ERASMUS) for drying as mentioned above. A certain thickness was required for the ultrasonic velocity measurements. However, wide cracks occurred on the samples of *FC4SB*, *FC6APB*, *FC7ACB* and *FC8ACB* which may be due to their high shrinkage behaviour. These finish coats are the materials which were recommended to be applied in maximum 0.08cm on building surfaces and were not available to produce thicker samples even for a thickness of 0.5cm for the analyses of mechanical properties.

The thicknesses for all samples were measured with vernier calipers of 0.01mm precision at four different points and the arithmetic mean of these four values was recorded as thickness, "*d*". After these operations samples were analyzed in terms of their material properties.

3.2 Analyses for Physical Properties

Physical properties of bulk density, porosity, water absorption capacity and water vapour permeability of the finish coats and undercoats were examined by the laboratory analyses (TSE 2000a; TSE, 1998; ASTM, 1992; TSE, 1990; TSE, 1987; Teutonico, 1986; RILEM, 1980). In addition, partial vapour pressure distribution in the externally and internally insulated single-leaf masonry walls was analyzed by means of calculation methods described in the standards (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969).

3.2.1 Determination of Bulk Density, Porosity and Water Absorption Capacity

For the analysis of the physical properties, the samples were completely submerged into distilled water during 48 hours, and then placed in vacuum by using HERAEUS vacuum chamber at 0.132 atm (100 torr) pressure for one hour. The weight of these samples were measured in air and recorded as saturated weight, "M_{sat}". Following this, the weight of the samples was measured in distilled water and recorded as Archimedes weight, "M_{arc}". Finally, the samples were dried in the ERASMUS oven at 40°C until reaching a constant weight, which was recorded

as the dry weight of the sample, "M_{dry}". All weights were measured with the sensitivity of 0.001 g and used for the calculations of porosity, bulk density and water absorption capacity of the samples (TSE, 1987; Teutonico, 1986).

Porosity "$\emptyset$" is the ratio of the pores or voids of a solid mass to the volume and expressed by the percentage of volume (RILEM, 1980; Teutonico, 1986). The porosity was calculated by the following formula (TSE, 1987):

$$\emptyset = \frac{M_{SAT} - M_{DRY}}{M_{SAT} - M_{ARC}} \times 100 \qquad \% \tag{1}$$

where,

M_{SAT}: saturated weight, g

M_{DRY}: dry weight, g

M_{ARC}: weight of the sample in water, g

Bulk density, "ρ", is the ratio of the mass to the bulk volume of the sample (RILEM, 1980; Teutonino, 1986). It is expressed in g/cm^3 and calculated by the following formula (TSE, 1987).

$$\rho = \frac{M_{DRY}}{M_{SAT} - M_{ARC}} \qquad g/cm^3 \tag{2}$$

Water Absorption Capacity, "θ_{max}", is the maximum quantity of water absorbed by a porous material immersed in distilled water and was expressed as percentage of

the dry mass of the sample (RILEM, 1980; Teutonino, 1986). It was calculated by the following formula (TSE, 1987).

$$\theta_{max} = \frac{M_{SAT} - M_{DRY}}{M_{DRY}} \times 100 \qquad \% \tag{3}$$

3.2.2 Determination of Water Vapour Permeability Properties

The principle for the analyses of water vapour permeability properties is to measure the amount of water vapour passing through the material per unit time, at controlled boundary conditions with a constant humidity and temperature at both sides of the specimen. The experimental procedure was determined according to the standards of RILEM, DIN, TSE and ASTM. The transmission of water vapour from 100%*RH* to 50%*RH* was recorded as a function of time. In the experiment, the sample was sealed to the open mouth of a water and water vapour proof plexiglass container filled with distilled water. A special care was given to keep 2 cm air gap at the top of the container for each assembly. In order to ensure the evaporation only from the top surface, all sides remained were sealed with melted paraffin. A small hole was opened on the plexiglass container by using a hot wire for the possibility of filling water in it if necessary. This assembly was placed in a desicator providing 50% $\pm$5%*RH*, at 23°C. The experimental setup is shown in Figure 3.9. (TSE, 2000; TSE 1999; Hedenblad, 1996; ASTM, 1992; TSE, 1990; Szczerba and Jedrzejewska, 1988; DIN, 1987; RILEM, 1980).

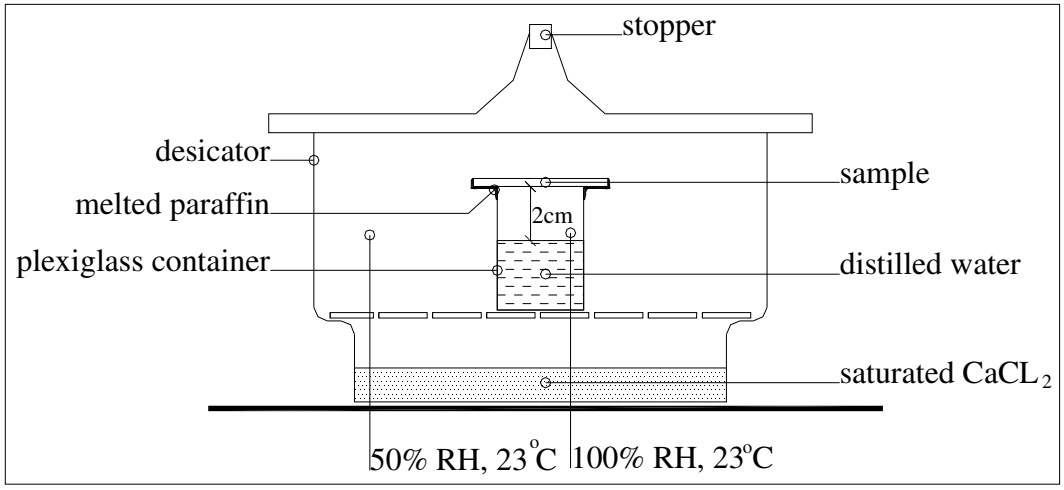


Figure 3.9. The experimental set-up for the analysis of water vapour permeability.

The thicknesses of the samples were recorded. The initial weight of each assembly, consisting of a plexiglass container filled with distilled water and of a sample was recorded. Their weights were measured periodically, every other day, with a precision of 0.001 g, until the weight change per unit time reached a constant value.

Water vapor transmission rate "R_T" is defined as the water vapour flow per unit time through unit area of a body, normal to its specific parallel surfaces, under specific conditions of temperature and humidity at each surface (TSE 1999; ASTM, 1992). It was calculated by the following formula (ASTM, 1992).

$$R_T = \frac{G}{t \times A} \qquad \text{g/hm}^2 \tag{4}$$

where;

G: weight change, in grams

t: time, in hours

A: test area (plexiglass container mouth area), in m²

According to the classification in Turkish Standards (1999), R_T values below 0.6g/hm^2 indicate low vapour permeability; R_T values between 0.6g/hm^2 and 6.0g/hm^2 indicate medium permeability and values higher than 6.0g/hm^2 correspond to high permeability.

Permeance is defined as the rate of water vapour transmission through unit area of a material induced by unit vapour pressure difference between two surfaces under specified temperature and humidity conditions (ASTM, 1992; DIN, 1987). It was calculated by the following formula (ASTM, 1992).

$$Permeance = \frac{R_T}{\Delta P} \times \frac{1}{3600} = \frac{R_T}{S \times (R_1 - R_2)} \times \frac{1}{3600} \quad \text{g/Pasm²} \qquad (5)$$

where;

ΔP: vapour pressure difference, in Pascals

S: saturation vapour pressure at test temperature, in Pascals

R_1: relative humidity in the controlled chamber, expressed as a percentage,

R_2: relative humidity in the dish, expressed as a percentage.

Permeance can also be expressed in "*perm (inch-pound)*" unit. 1 perm is equal to 5.72x10^{-8} g/Pasm² and 1 g/Pasm² is equal to 1.75x10^7 perm (ASTM, 1992).

Equivalent air layer thickness of water vapour diffusion "S_D" indicates the thickness of a motionless air layer which has the same moisture resistance as the specimen with the thickness "*d*" (TSE, 1999; TSE, 1990; DIN, 1987). It was calculated by the following formula (TSE, 1990);

$$S_D = \left[\frac{\delta_L \times A \times (P_1 - P_2)}{I} \right] - S_L \qquad \text{m} \tag{6}$$

where,

δ_L : constant = 6.89 x 10^{-6} (kg/hm(kg/m^2))

A: test area (area of dish mouth), in m^2

P1: partial vapour pressure in the controlled space, in kg/m^2

P2: partial vapour pressure in the dish, in kg/m^2

I: weight change per unit time, in kg/hr

S_L: thickness of air beneath the sample, in meters.

It was also possible to classify materials according to their S_D values (TSE, 1999). As described in this standard, S_D values over 1.4 m indicate low water vapour permeability; S_D values between 1.4 m and 0.14 m indicate medium water vapour permeability and values lower than 0.14 m correspond to high water vapour permeability. For this reason, same samples were analyzed also according to their S_D values. The total S_D of a wall section is the sum of the S_D values of its components/layers (İzocam, 2004; TSE; 1999; TSE, 1998; Akkuzugil, 1997).

$$S_D = S_{D1} + S_{D2} + S_{D3} + ... + S_{Dn} \qquad \text{m} \tag{7}$$

Permeability is the water vapour permeability value of a material for a given thickness (TSE, 1990). It was calculated by the following formula (TSE, 1990).

$$Permeability = \frac{1}{S_D} \quad 1/\text{m} \tag{8}$$

Water vapour diffusion resistance index "μ" is the resistance to the water vapour permeation. It indicates how many times greater the moisture resistance of the material is in comparison with the resistance of a motionless layer of air of the same thickness at the same temperature (TSE, 1990; DIN, 1987). It was calculated by the following formula (TSE, 1990; DIN, 1987).

$$\mu = \frac{S_D}{d} \tag{9}$$

where,

S_D: water vapour diffusion equivalent air thickness, in meters

d: thickness of the sample, in meters

3.2.3 Analysis of Partial Vapour Pressure Distribution in the Wall Sections

In order to investigate the risk of condensation in the wall sections, partial vapour pressure (p) and equilibrium vapour pressure (p_s) were calculated for externally and internally insulated brick masonry walls, insulated with 5 cm thickness *XPS* board and plastered with acrylic copolymer-based finish coat *FC7ACB* (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969). For these calculations the

boundary conditions were assumed to be 21°C and 50% RH at interior and 5.5°C and 80% RH at exterior which were the mean values of 5 months in cold seasons of Turkey for the region "3" (İzocam, 2004; TSE, 1998)

Partial vapour pressure "*p*" is the pressure of water vapour at given temperature and humidity conditions. It was calculated as follows (İzocam, 2004; TSE, 1998).

$$p = \varphi \times p_s \quad \text{Pa} \qquad (10)$$

where,

p: partial vapour pressure, in Pascals

φ: relative humidity, in persentage

p_s: equilibrium water vapour pressure at a given temperature, in Pascals (AppendixA).

In order to find out the distribution of equilibrium water vapour pressure in externally or internally insulated single leaf masonry walls, temperature at each layer in the wall section was calculated. For this purpose, temperature differences between interior and exterior, ΔT, thermal resistance values, R_n, heat flow, Q, and temperature drops, ΔT_n, in the wall sections were determined (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969).

Temperature difference "ΔT" was calculated as follows (İzocam, 2004; TSE,1998; Strother and Turner, 1990; BRE,1969).

$$\Delta T = T_i - T_e \quad °C \tag{10}$$

where;

T_i: interior air temperature, in °C

T_e: exterior air temperature, in °C.

Thermal resistance, "R_n" is the resistance of a material for a given thickness to the thermal conduction and calculated as follows (İzocam, 2004; TSE, 1998; Everett, 1994; Strother and Turner, 1990; BRE, 1969).

$$R_n = \frac{d_n}{k_n} \qquad m^2°C/W \tag{11}$$

where,

d_n: the thickness of the material, in meters

k_n: thermal conductivity coefficient of the material, in W/m°C. (Appendix B).

Total thermal resistance, "R_t" is the sum of the thermal resistance of materials used in the wall section and calculated as follows (TSE, 1998; Strother and Turner, 1990; BRE, 1969).

$$R_t = R_i + R_1 + R_2 + ...R_n + R_e \qquad m^2°C/W \tag{12}$$

where,

R_i: thermal resistance of interior, in $m^2°C/W$

R_n: thermal resistance of the material, in $m^2°C/W$

R_e: thermal resistance of exterior, in $m^2°C/W$.

Heat flow "Q" is the ratio of temperature difference of air between inside and outside of the wall to the total thermal resistance (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969).

$$Q = \frac{\Delta T}{R_t} \qquad \text{W/m}^2 \tag{13}$$

where,

ΔT: temperature difference, in °C

R_t: total thermal resistance, in m^2°C/W

Temperature drop between layers of wall "ΔT_n" was calculated as follows (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969).

$$\Delta T_n = Q \times R_n \quad \text{°C} \tag{14}$$

where,

Q: heat flow, in W/m^2

R_n: thermal resistance of the material, in m^2°C/W.

Using the formulas given above, temperature for each layer surface was calculated for a wall section insulated externally and internally by *Ti1XPS* and coated with *FC7ACB*. Results were presented in figures where partial vapour pressure was assumed to decrease linearly from interior to exterior. (Figure 3.10 and Appendix A). While, the surfaces where the equilibrium water vapour pressure was greater than the partial water vapour pressure were not under the risk of condensation, on

the surfaces where these two pressures were equal to each other, condensation would surely occur (İzocam, 2004; TSE, 1998; Strother and Turner, 1990; BRE, 1969).

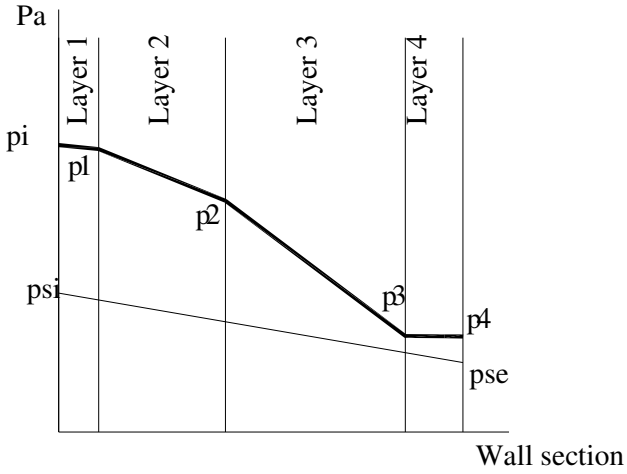


Figure 3.10. Partial and equilibrium water vapour pressure distribution in a wall where, there is no risk of condensation.

3.3 Analyses for Mechanical Properties

In this study, ultrasonic pulse velocity (*UPV*) values and bulk density of the samples were determined in order to calculate modulus of elasticity (E_{mod}) of the samples (ASTM, 1990; RILEM, 1980).

3.3.1 Determination of Modulus of Elasticity (Young's Modulus)

The modulus of elasticity (E_{mod}) is defined as the ratio of stress to strain and indicates the deformation ability of a material under external forces (Timoshenko 1970). For the measurements of the *UPV*, a pulse generator, PUNDIT*plus*, with its probes, transmitter and receiver of 220kHz, for small sized samples were used. In this method, the transducers (transmitter and receiver) were marked on the samples parallel to each other and on the same line perpendicular to the samples. The time required for the ultrasonic waves to traverse the minimum cross section of the specimen was measured. At least six readings from four different points were recorded for each sample. The velocities of the waves (v) were calculated by the following formula (ASTM, 1990; RILEM, 1980).

$$V = \frac{d}{t} \qquad \text{m/s} \tag{15}$$

where,

d: distance traversed by the wave, in meters

t: travel time, in seconds.

The modulus of elasticity "E_{mod}" is then obtained through the bulk density of the specimen and velocity by the following formula (RILEM, 1980).

$$E_{\text{mod}} = \frac{\rho \times V^2 \times (1+\nu_{dyn}) \times (1-2\times\nu_{dyn})}{1-\nu_{dyn}} \qquad \text{N/m}^2 \tag{16}$$

where,

ρ: bulk density of the specimen, in g/m^3,

V: velocity, in m/s,

ν_{dyn}: Poison's ratio

Poison's ratio refers to the ratio of lateral expansion to the longitudinal reduction of the material under compression (Timoshenko 1970). In relation to the elasticity of different building materials, Poison's ratio differs from 0.1 to 0.5. Considering the similarities between mortar and lightweight concrete, 0.18 was found to be a reasonable value for v_{dyn} to be used in the finish coats and undercoats. E_{mod} values were expressed in GPa in the related tables and diagrams.

CHAPTER 4

RESULTS

Results of the laboratory analyses and the calculations are given in this section, presented together or in succession with figures and tables and summarized in the following sections.

4.1 Physical Properties

Data obtained from the experimental results exhibited the basic physical properties of the finish coats and undercoats in terms of bulk density (ρ), porosity ($\emptyset$), water absorption capacity (θ_{max}) and water vapour permeability. An emphasis was given to water vapour permeability properties of the samples in respect to their water vapour transmission rate (R_T), permeance, equivalent air layer thickness of water vapour diffusion (S_D), permeability ($1/S_D$) and water vapour diffusion resistance index (μ). The continuity of the water vapour flow through the layers of wall sections were also examined by means of calculations using the empirical data and real thicknesses. The distribution of partial water vapour pressure along the wall sections were also analyzed to better understand the relation between the risk areas of condensation and necessity of the continuity in the permeability.

4.1.1 Bulk Density, Porosity and Water Absorption Capacity

The bulk density, porosity and water absorption capacity values of finish coats and undercoats are given in Table 4.1 and Figure 4.1. The bulk density of the finish coats was found to be in a wide range of 1.11 ±0.03g/cm^3 and 1.94 ±0.07g/cm^3, with a mean of 1.50 $\pm$0.28g/cm^3. In this range, cement-based finish coat was observed to have the highest density, while the synthetic-based ones had lower density and the acrylic polymer-based ones had the lowest density with the mean values of 1.94 ±0.07g/cm^3, 1.55 $\pm$0.11g/cm^3 and 1.18 $\pm$0.10g/cm^3, respectively. The mean values for their porosity and water absorption capacities were found to be 25.5±2.1%, 37.7$\pm$5.2%, 48.7$\pm$2.1% and 13.2±1.5%, 24.6$\pm$5%, 41.7$\pm$5.1% respectively.

The bulk density of the cement-based undercoats was found to vary in the range of 1.74±0.07g/cm^3 and 1.93±0.01g/cm^3, with a mean of 1.85$\pm$0.1g/cm^3. Their porosity and water absorption capacities were found to be in the range of 22.4±0.8% and 27.6±1.2% with a mean of 25.4$\pm$2.7 % and 11.6±0.4% and 15.9±1.3% with a mean value of 13.9$\pm$2.2%, respectively. Cement-based finish coats and undercoats were observed to have similar physical properties.

Table 4.1. Bulk density, porosity and water absorption capacities of the finish and undercoats.

Name of the sample	Bulk density, ρ (g/cm3)	Porosity, Ø (%)	WAC, θmax (%)
FC1SB	1.49±0.03	40.6±1.1	27.3±1.3
FC2SB	1.68±0.04	30.5±1.9	18.1±1.5
FC3SB	1.44±0.15	42.1±5.9	29.7±6.9
FC4SB	1.60±0.12	37.6±1.9	23.5±0.8
FC5CB	1.94±0.07	25.5±2.1	13.2±1.5
FC6APB	1.11±0.03	50.1±1.5	45.3±2.5
FC7ACB	1.25±0.09	47.2±4.0	38.1±5.6
UC2CBF	1.93±0.01	22.4±0.8	11.6±0.4
UC1CBR	1.87±0.04	26.3±1.4	14.1±0.9
UC3CBT	1.74±0.07	27.6±1.2	15.9±1.3

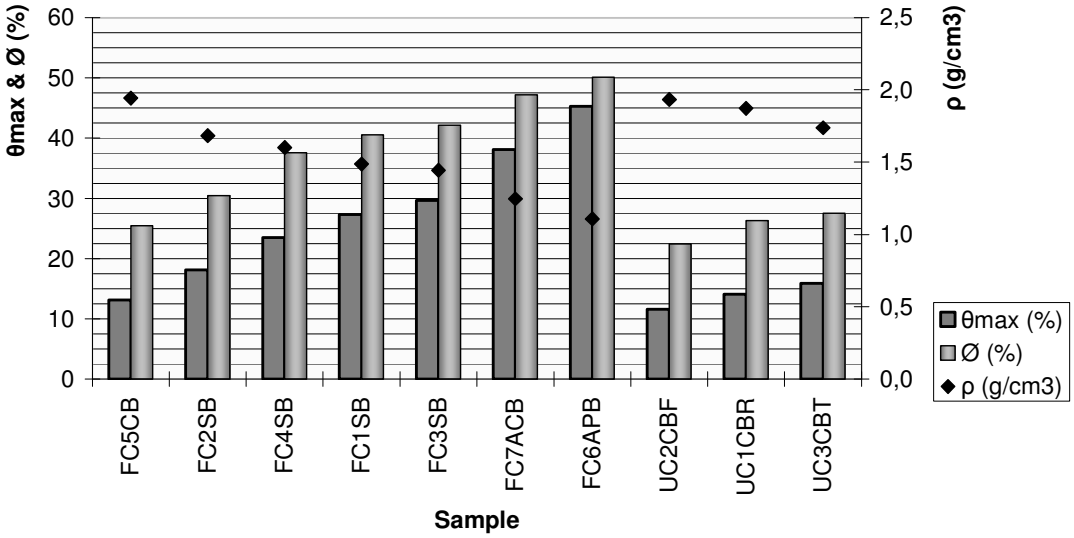


Figure 4.1 Bulk density (ρ), porosity ($\emptyset$) and water absorption capacity (θ_{max}) of the samples of finish and undercoats.

4.1.2 Water Vapour Permeability Properties

The results of the water vapour permeability analyses and the real thicknesses used in the calculations were given in the Table 4.2. According to the R_T values,

the finish coats, individually, were found to be high permeable varying in a wide range of 5.9±0.2g/hm^2 and 14.8±1.0g/hm^2 with a mean value of being 9.0±2.9g/hm^2 (TSE, 1999). Among these, polymer-based *FC8ACB* was determined as the highest permeable finish coat while synthetic-based *FC2SB* was the lowest permeable one. The application of primer was found to change the permeability properties of some finish coats (Figure 4.2). The total R_T values were found to be in the range of 4.2±0.1g/hm^2 and 10.6±0.3g/hm^2. The effect of primer to the permeability was different from one sample to another. The primer seemed to considerably decrease the permeability of polymer-based finish coats with a mean R_T of 5g/hm^2, except *FC7ACB*. On the other hand, primer seemed to slightly decrease the permeability of synthetic-based finish coats, *FC1SB* and *FC3SB*, with a mean R_T of 0.6g/hm^2. The decrease in the R_T values of *FC2SB*, *FC4SB* and *FC7ACB* were found 2.0 g/hm^2 in average. In summary, with the application of primer or paint, *FC2SB*, *FC4SB, FC5CB* became medium permeable layers, while the others remained still high permeable (TSE, 1999).

Table 4.2 Water vapour permeability values of the samples.

Sample	Th. (d), mm	RT, g/hm^2	Permeance g/Pasm^2	Perm	SD, m	1/ SD, 1/m	μ
FC1SB	3.0	7.4±0.3	1.75±0.07x10^{-6}	30.61±1.27	0.092±0.005	10.9±0.6	30.6±1.5
Pr1SB+FC1SB	0.1+3	6.7±0.6	1.59± 0.1x10^{-6}	27.81±2.61	0.104±0.012	9.7±1.1	N.A.
FC2SB1	3.0	5.9±0.2	1.41± 0.05x10^{-6}	24.64±0.96	0.119±0.005	8.4±0.4	39.6±1.8
Pr1SB+FC2SB	0.1+3.0	4.2±0.1	9.88± 0.2x10^{-7}	17.28±0.37	0.178±0.004	5.6±0.1	N.A.
FC3SB1	3.0	8.8±0.6	2.09± 0.1x10^{-6}	36.63±2.54	0.074±0.007	13.6±1.2	24.5±2.2
Pr1SB+FC3SB	0.1+3.0	8.3±0.1	1.98± 0.02x10^{-6}	34.62±0.40	0.079±0.001	12.7±0.2	N.A.
FC4SB	3.0	7.0±0.2	1.65± 0.05x10^{-6}	28.93±0.87	0.098±0.004	10.2±0.4	32.7±1.2
Pr1SB+FC4SB	0.1+3.0	4.5±0.2	1.06± 0.04x10^{-6}	18.61±0.64	0.164±0.006	6.1±0.2	N.A.
FC5CB	3.0	8.8±0.8	2.09± 0.2x10^{-6}	36.62±3.21	0.074±0.008	13.6±1.5	24.6±2.7
Pa1ACB+FC5CB	0.1+3.0	5.3±0.5	1.25±0.1x10^{-6}	21.81±2.22	0.138±0.016	7.3±0.9	N.A.
FC6APB	0.8	11.3±0.6	2.69±0.1 x10^{-6}	47.05±2.44	0.053±0.004	19.0±1.4	65.9±4.7
Pr1SB+FC6APB	0.1+0.8	5.7±0.2	1.36± 0.05x10^{-6}	23.79±0.86	0.124±0.005	8.1±0.3	N.A.
FC7ACB-	0.8	7.8±1.4	1.85± 0.3x10^{-6}	32.36±5.90	0.088±0.022	11.3±2.6	110.3±27.4
Pr1SB+FC7ACB	0.1+0.8	6.0±0.1	1.44± 0.02x10^{-6}	25.12±0.32	0.116±0.002	8.6±0.1	N.A.
FC8ACB-	0.8	14.8±1.0	3.52± 0.2x10^{-6}	61.56±4.03	0.036±0.004	28.1±2.9	44.5±4.4
Pr1SB+FC8ACB	0.1+0.8	10.6±0.3	2.53± 0.07x10^{-6}	44.20±1.14	0.057±0.002	17.5±0.6	N.A.
UC1CBR	20	1.5±0.2	3.45± 0.5x10^{-7}	6.04±0.84	0.552±0.074	2.2±0.3	27.6±3.7
UC2CBF	10	3.5±0.3	8.33± 0.7x10^{-7}	14.58±1.27	0.215±0.021	3.0±0.4	21.5±2.1
UC3CBT	8	2.3±0.4	5.55± 0.9x10^{-7}	9.72±1.62	0.341±0.069	2.9±0.5	42.6±8.6
Pr1SB	0.1	30.6±1.0	7.26± 0.2x10^{-6}	127.0±3.97	0.007±0.001	144.7±19	69.1±8.3
Ti1XPS	50	0.1±<0.01	2.84± 0.05x10^{-8}	0.50±0.01	6.858±0.111	0.1±<0.1	137.2±2.2
Ti2EPS	50	0.3±0.02	7.15± 0.4x10^{-8}	1.25±0.07	2.714±0.152	0.4±<0.1	54.3±3.0
Ti3RW	50	4.5±0.2	1.06± 0.04x10^{-6}	18.56±0.69	0.164±0.007	6.1±0.3	3.3±0.1
Pa1ACB	0.1	30.6±0.7	7.27± 0.2x10^{-6}	127.3±2.79	0.007±0.001	146.2±13	68.4±5.9
Ma1BM	190	0.9	2.01x10^{-7}	3.52	0.950	1.1	5.0
Ma2AAC	200	0.9	2.19x10^{-7}	3.84	0.870	1.1	4.4
Pl1CLB	20	2.6	6.10 x10^{-7}	10.67	0.300	3.3	15.0
GB1GB	12.5	10.1	2.37x10^{-6}	41.40	0.065	16.0	5.0

N.A.: not available; refers to the values that can not be calculated, especially for the samples constituted of more than one layer.

For the samples of Ma1BM, Ma2AAC, Pl1CLB and GB1GB the data was calculated by using the μ value taken from the literature (Andolsun et al., 2006; İzocam,, 2004; TSE, 1998).

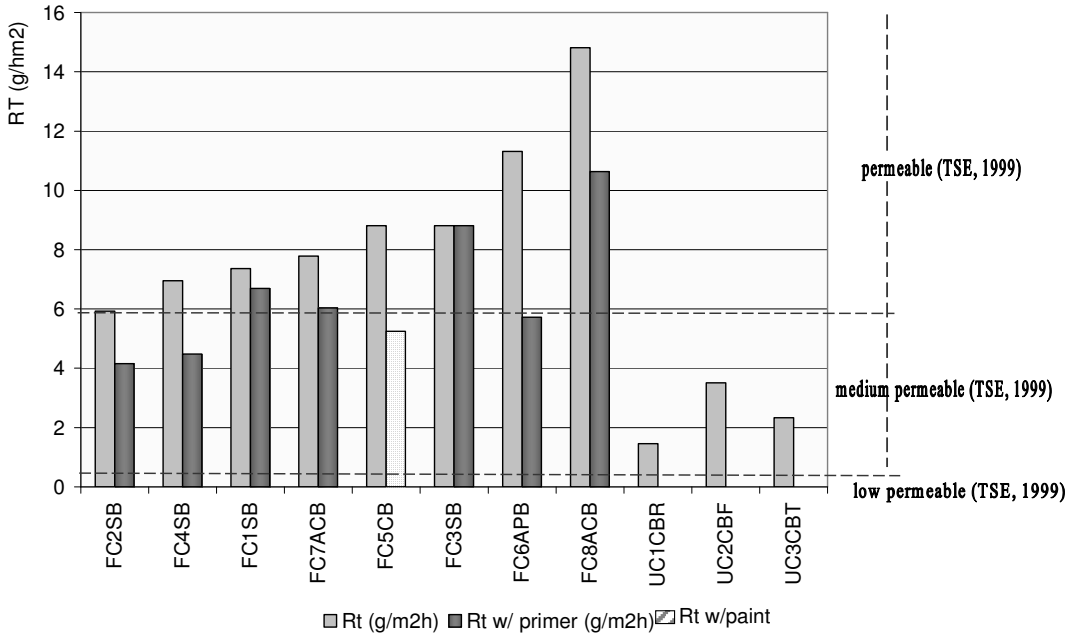


Figure 4.2. R_T values of the finish coats and undercoats.

The R_T value of the cement-based *FC5CB* was 5.3g/hm^2 and 8.8g/hm^2 for the painted and unpainted samples respectively. According to the same classification, this finish coat was found to become medium permeable after the application of paint. On the other hand, other cement-based coats, $UC1CB_R$, $UC2CB_F$ and $UC3CB_T$ were found to be medium permeable with R_T values of 1.5 g/hm^2, 3.5g/hm^2 and 2.3 g/hm^2 respectively.

The permeance values of the finish coats ranged from 1.41x10^{-6}g/Pasm^2 to 3.52x10^6 g/Pasm^2 with a mean of 2.13±0.7x10^{-6}g/Pasm^2. Perm values varied between 24.64±0..96perm and 61.56±4.03perm (Table 4.2). The permeance and perm values were found to be parallel with R_T values as expected.

All finish coats were found to be high vapour permeable due to their S_D values in the range of 0.036±0.04m and 0.119±0.005m, which were below the threshold of 0.14m (Table 4.2 and Figure 4.3) (TSE, 1999). Among all, polymer-based finish coats, *FC8ACB*, *FC6APB* and *FC7ACB* were found to have low S_D values; 0.036±0.004m, 0.053±0.04m and 0.088±0.022m, respectively, although their μ values were considerably high, even above the ranges of 15 to 35 given in the literature for the calculation of quantity of condensation (Pfeifer et al., 2001). These low S_D values were provided by their application in thin layers of 0.8mm thickness. The synthetic-based finish coats, *FC3SB*, *FC1SB*, *FC4SB* and *FC2SB* were found to have S_D values of 0.074±0.007m, 0.092±0.005m, 0.098±0.004m and 0.119±0.005m, respectively. Although it's being a cement-based finish coat, the S_D value of *FC5CB* was found to be 0.074±0.008m, which exhibited higher water vapour permeability than some synthetic- and polymer- based finish coats.

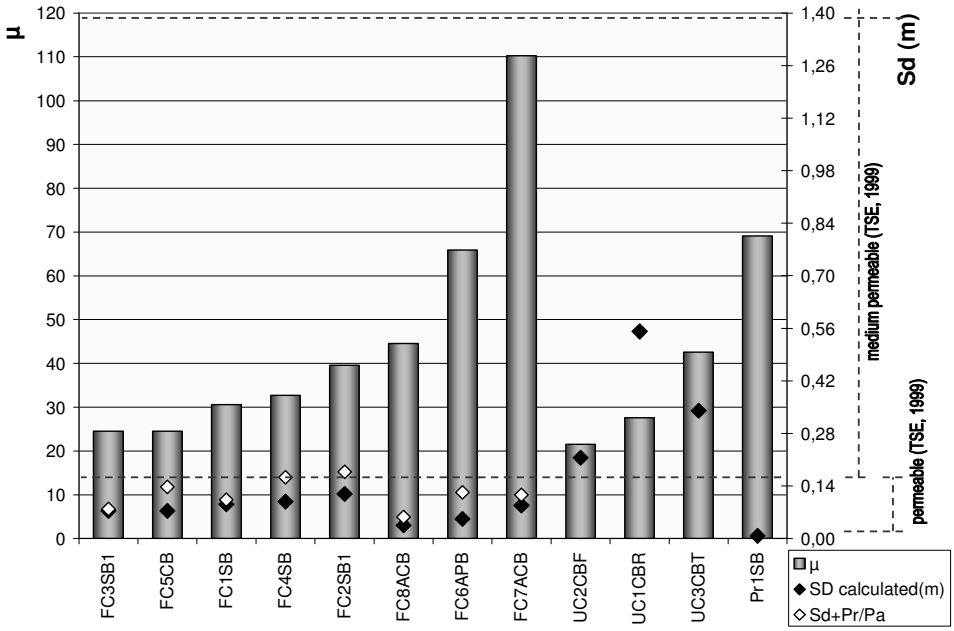


Figure 4.3 μ values of the samples, in relation to their S_D values when used with or without primer.

The synthetic-based primer *Pr1SB* had a very high μ value of 69.1±8.3 when compared to the finish coats and undercoats. It was however, found to be much more vapour permeable than the others with S_D value of 0.007±0.001m due to its application in a very thin layer of 0.1mm.

The effect of primer to the permeability properties of the finish coats was also determined by comparison of S_D values for finish coats individually and together with primer. As observed in the results of R_T values, the application of primer was found to decrease the water vapour permeability of finish coats in varying amounts (Table 4.2 and Figure 4.3). The S_D values for the samples of finish coat together with primer were found to be in the range of 0.057±0.002m and 0.183±0.178m. The synthetic-based *FC4SB* and *FC2SB* became medium permeable layers, with an average increase of 0.063m in their S_D values, after the application of primer. On the other hand, a slight increase of 0.008m in average was determined in S_D values of other synthetic-based finish coats, *FC1SB* and *FC3SB*. The layer of primer seemed to increase the S_D value of the polymer-based *FC6APB* considerably, with an increase of 0.071m, while still being high permeable. The same primer, however, seemed to affect slightly the S_D values of copolymer-based finish coats *FC7ACB* and *FC8ACB* with an average increase of 0.025m.

According to the results of the permeability analyses of the acrylic copolymer-based exterior paint, *Pa1ACB*, examined individually, it was found to have a high μ value of 68.4±5.9 while having a very low S_D value, 0.007±0.001m, due to its very thin application. However, its use on cement-based finish coat, *FC5CB*, increased the S_D

value of *FC5CB* considerably with an increase of 0.064m instead of 0.007m and made the finishing layer medium permeable.

Cement-based undercoats, $UC2CB_F$, $UC1CB_R$ and $UC3CB_T$ had μ values of 21.6±2.1, 27.6±3.7 and 42.6±8.6 and S_D values 0.215±0.021m, 0.552±0.074m and 0.341±0.069m, respectively (Figure 4.3). According to these results, all undercoats examined were found to be medium permeable materials.

Thermal insulation materials, *XPS*, *EPS* and rockwool, were determined to have different μ values. While *XPS* and *EPS* had μ values of 137.2±2.2 and 54.3±3.0, respectively, the rockwool had noticeably lower μ value of 3.3±0.1. When the S_D values were calculated for 5cm thick samples as mentioned in the previous chapter, *XPS* and *EPS* were found to be low permeable with S_D values of 6.858±0.11m and 2.714±0.152m, while rockwool was found to be medium permeable with S_D value of 0.164±0.007m although having a very low μ value. It should be noted that its S_D value was found to be very close to high permeable threshold of 0.14m (TSE, 1999).

Continuity of the water vapour transmission along the layers of the externally and internally insulated single-leaf exterior wall sections were examined by the S_D values calculated for each layer and summarized in Table 4.3 and Table 4.4, respectively. Among all finish coats, the most water vapor permeable one was found to be *FC8ACB*, when the real application of the coats together with primer or paint was considered. Synthetic-based *FC2SB* and *FC4SB* were found to be the

least permeable finish coats, with S_D values above 0.14m, which is the threshold of high permeability to medium permeability.

Table 4.3 The range of S_D values for each layers of externally insulated wall. The sum of SD layers for each layer gives the total S_D of wall section.

Internal finish		Masonry		Thermal insulation		Under coat		Finish coats (w/primer or paint)	
Pl1CLB	0.300	Ma1BM	0.950	Ti1XPS	6.858	UC3CBt	0.341	Pr1SB+FC1SB	0.104
								Pr1SB+FC2SB	0.178
								Pr1SB+FC3SB	0.079
				Ti2EPS	2.714			Pr1SB+FC4SB	0.164
		Ma2AAC	0.870					Pa1ACB+FC5CB	0.138
								Pr1SB+FC6APB	0.124
				Ti3RW	0.164			Pr1SB+FC7ACB	0.116
								Pr1SB+FC8ACB	0.057

Table 4.4 The range of S_D values for each layers of internally insulated wall. The sum of SD layers for each layer gives the total S_D of wall section.

Internal finish		Thermal insulation		Masonry		Under coat		Under coat		Finish coats (w/primer or paint)	
GB1GB	0.063	Ti1XPS	6.858	Ma1BM	0.950	UC1CBr	0.552	UC2CBf	0.215	Pr1SB+FC1SB	0.104
										Pr1SB+FC2SB	0.178
										Pr1SB+FC3SB	0.079
		Ti2EPS	2.714							Pr1SB+FC4SB	0.164
				Ma2AAC	0.870					Pa1ACB+FC5CB	0.138
										Pr1SB+FC6APB	0.124
		Ti3RW	0.164							Pr1SB+FC7ACB	0.116
										Pr1SB+FC8ACB	0.057

When the undercoats of the externally and internally insulated wall sections were compared, it was found that the total S_D value of the undercoats $UC1CB_R$ and $UC2CB_F$, which were used in internally insulated walls, was higher than the $UC3CB_T$, which is used in internally insulated walls. It was, on the other hand, observed that the undercoats of the both systems were medium permeable and found to disturb the water vapour transmission along the wall section.

All thermal insulation materials were found to prevent the passage of the water vapour through the wall section significantly. Among the three insulation layers, the polystyrene-based *XPS* and *EPS* were found to be low permeable with S_D values considerably higher than rockwool which was determined as medium permeable insulation board. In this respect, considering that the usage of the thermal insulation is obligatory in Turkey (TSE, 1998), mineral-based rockwool was found to be more advantageous than the polystyrene-based thermal insulation layers.

The total S_D value of a wall section is the sum of S_D values of the materials used in the section. The total S_D values were calculated to be in the range of 1.732m to 8.627m for an externally insulated wall and in the range of 1.921m to 8.816m for an internally insulated wall. The main reason of these wide ranges was the great differences in S_D values varying according to the type of thermal insulation layers.

As an example to follow the permeability characteristics of layers in a wall section, Figures 4.4 and 4.5 and Figures 4.6 and 4.7 were produced. Some figures showing the S_D and R_T values, as a function of layers of externally and internally insulated

walls, constructed with 19cm brick, 5cm insulation board and exterior finishing system using *FC7ACB*, were prepared. They were used to analyze the continuity of water vapour permeability through the layers of the wall section.

The Figures 4.4 and 4.5, produced by adding up the S_D values of each layer as a function of layer thickness and the slope of the line gave the μ value of each layer. The higher slope indicated higher μ value, in other words higher resistance to water vapour permeation. The interruption of the continuity in the water vapour permeability is mainly observed in the insulation layers, the most at *XPS* layer and more at *EPS*. In the cases where rockwool is used as thermal insulation material, the water vapour transmission flow was found to be more favorable than the other cases. In addition, it was noticed that the slope of the line increased considerably at the layers of the masonry and undercoats, where the water vapour flow is again interrupted by these medium permeable layers.

In Figures 4.6 and 4.7, R_T values of all samples were presented. From these figures, the change in the permeability characteristics of the finish coats was noticed to change from high permeable to medium permeable. It was observed that acrylic copolymer-based *FC8ACB* performed better in terms of water vapour permeability, when compared to other finish coats. Synthetic-based *FC2SB* was found to be the least permeable finish coat (TSE, 1999) with an R_T value between 0.6 g/hm^2 and 6g/hm^2. The interruption of the water vapour permeability along the wall section by the medium permeable layers of the masonry, undercoat and rockwool and low permeable layers of *XPS* and *EPS* was also noticeable.

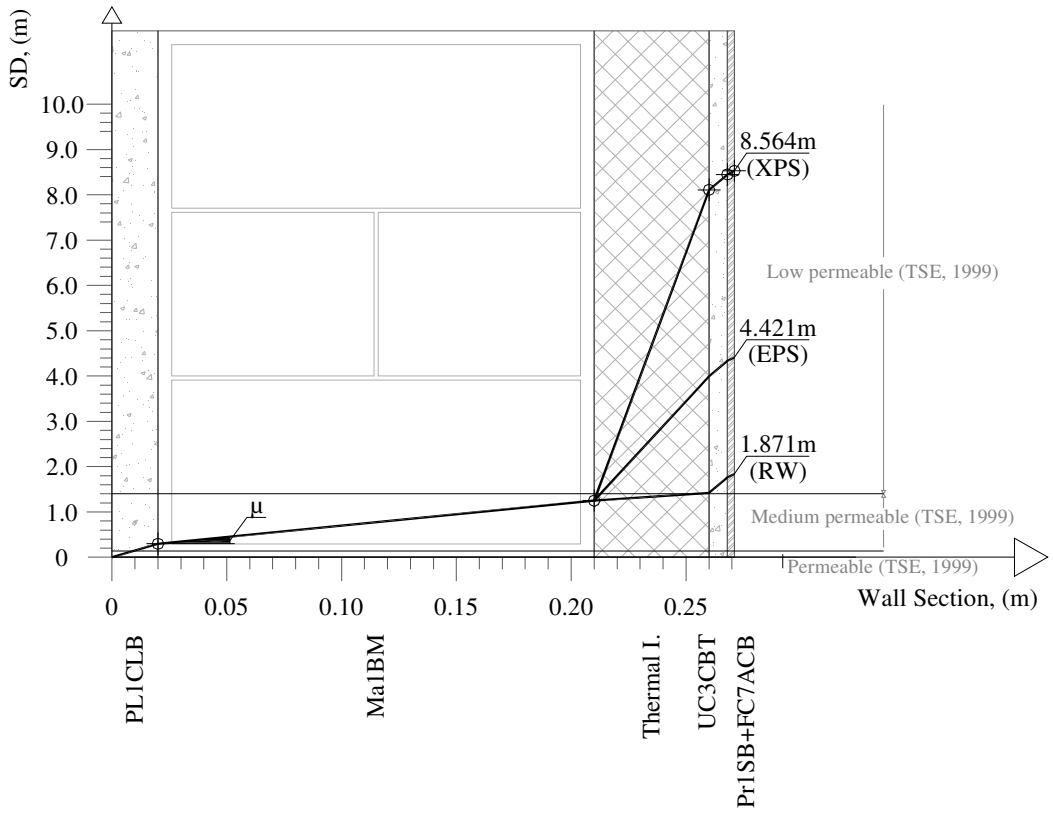


Figure 4.4. Total S_D values in an externally insulated wall section plastered with *FC7ACB*.

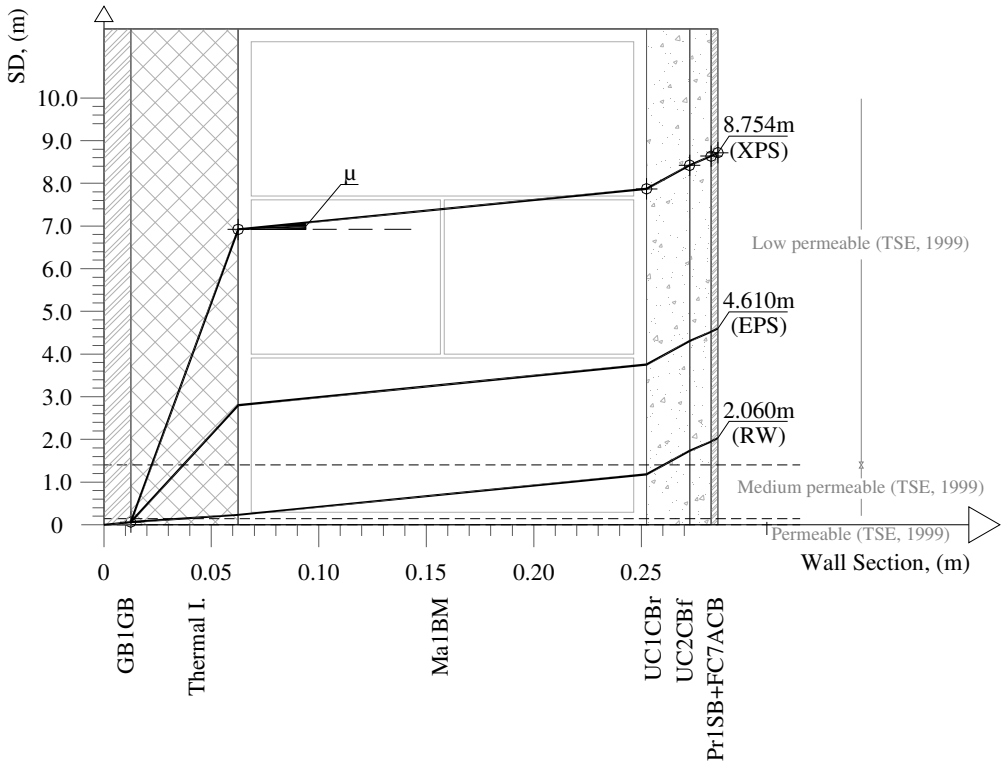


Figure 4.5. Total S_D values in an internally insulated wall section plastered with *FC7ACB*.

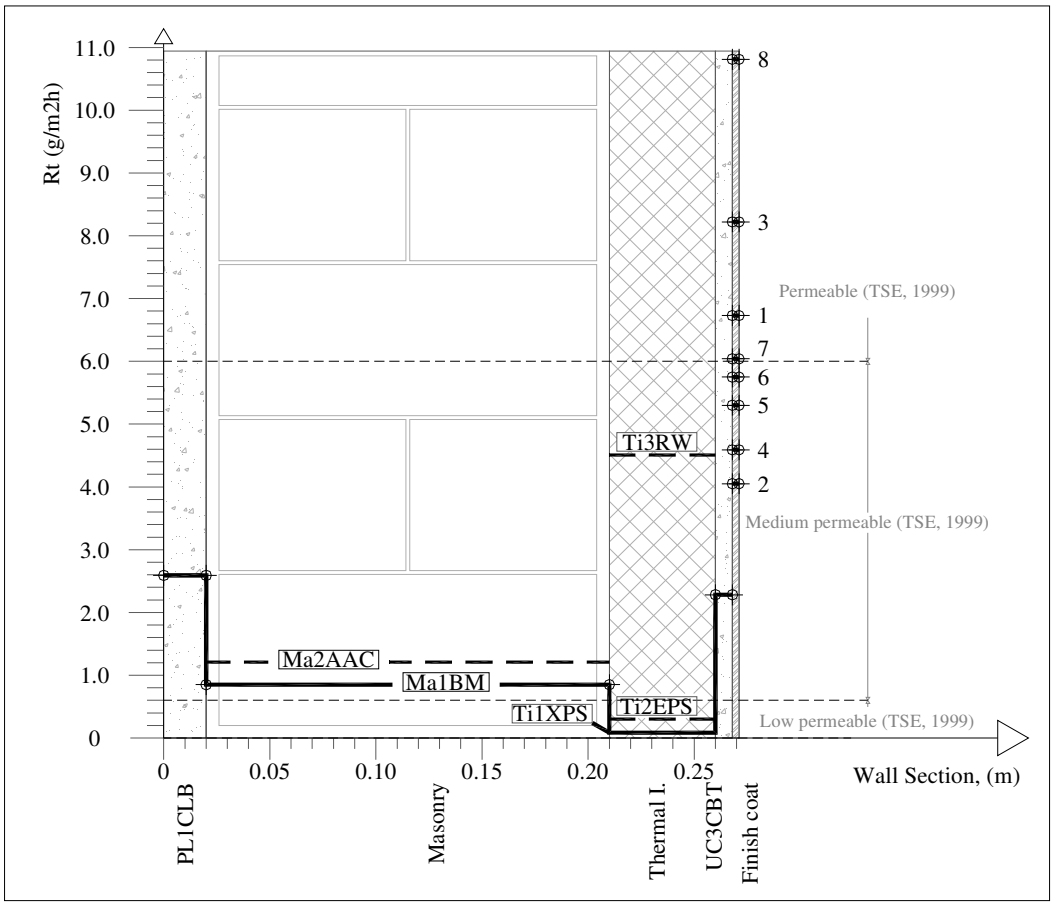


Figure 4.6. R_T values for each layer of an externally insulated wall section. The numerical arrangement in the external face presented the sample number of finish coat, for example *FC3SB* is presented by 3.

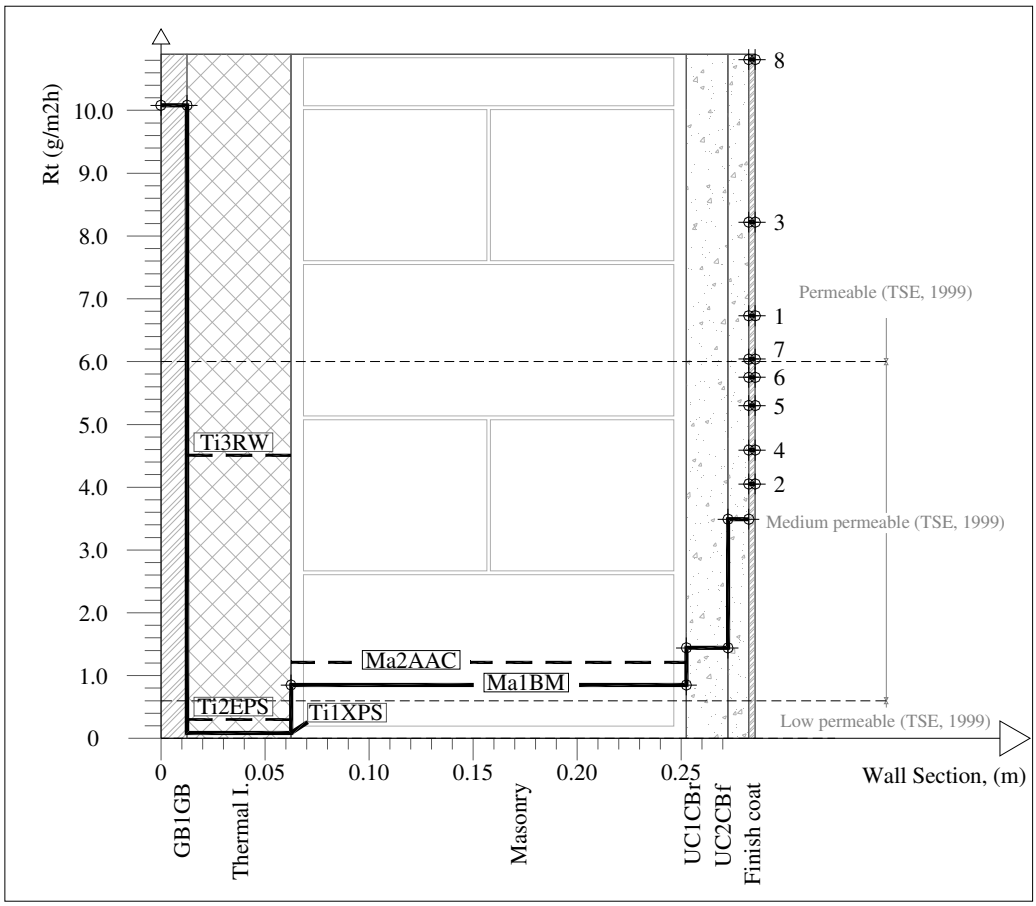


Figure 4.7. RT values for each layer of an internally insulated wall section. The numerical arrangement in the external face presented the sample number of finish coat, for example FC3SB is presented by 3.

4.1.3 Partial Water Vapour Pressures

The results of the water vapour pressure calculations for externally and internally insulated walls were given in Figures 4.8 and 4.9., respectively. For the calculations, the boundary conditions of 21°C and 50% RH at interior and 5.5°C and 80% RH at exterior were taken as the mean values of 5 months in cold seasons of Turkey for the region "3" (İzocam, 2004; TSE, 1998) and thermal conductivity

values of each layer were taken into account for the determination of temperature differences between the layers (Appendix B). In these figures, the distribution of partial water vapour pressures from interior (p_i) to exterior (p_e) and equilibrium water vapour pressure (p_s) were shown in the figures of water vapour pressure (Pa) as a function of S_D (m). The partial pressures of both externally and internally insulated walls were found to be lower than the equilibrium vapour pressures along the wall sections. It seemed to have no risk of surface or interstitial condensation in these wall sections, for the case of boundary conditions given in standards.

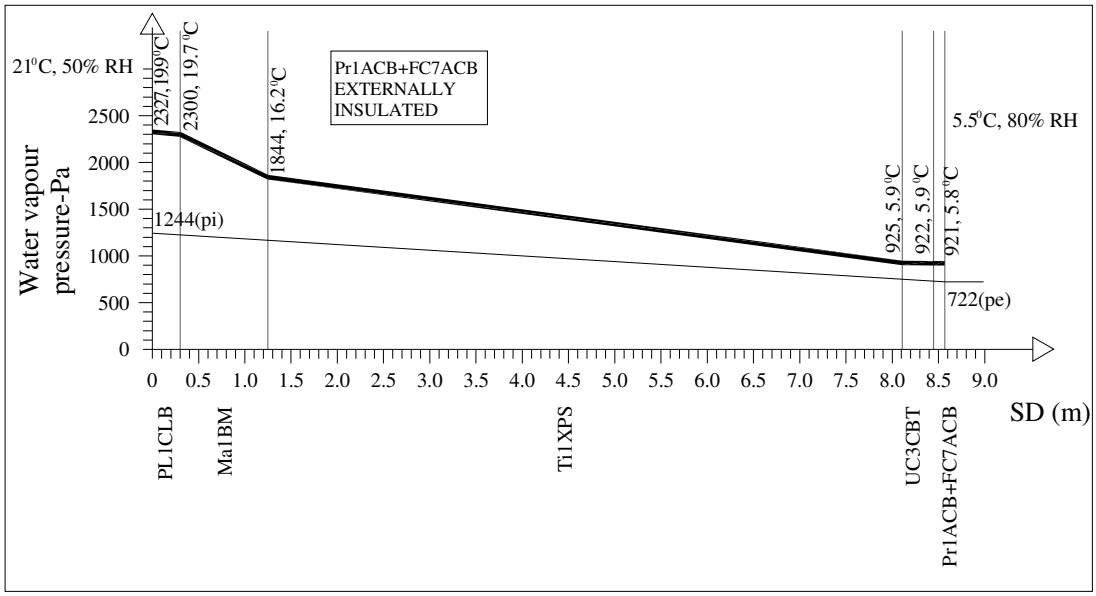


Figure 4.8. Partial (p_i and p_e) and equilibrium (p_s) water vapour pressure distribution for an externally insulated wall section coated by *FC7ACB*.

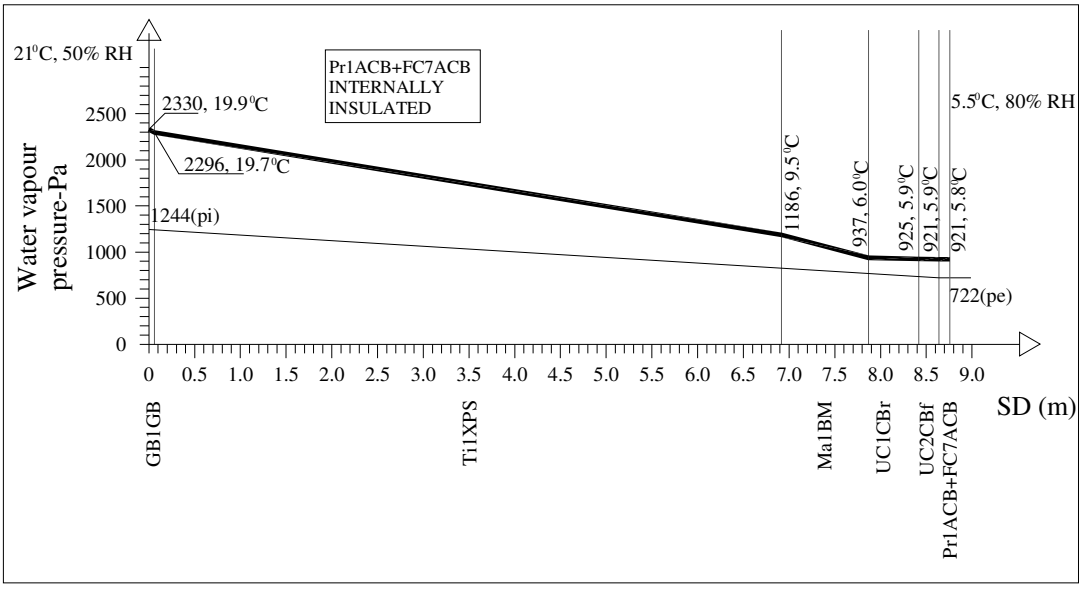


Figure 4.9. Partial (p_i and p_e) and equilibrium (p_s) water vapour pressure distribution for an internally insulated wall section coated by *FC7ACB*.

4.2 Mechanical Properties

The data obtained from the experiments exhibited the mechanical properties of the finish coats and undercoats in terms of their ultrasonic pulse velocity (*UPV*) and modulus of elasticity (E_{mod}). The results are given in the following section.

4.2.1 Ultrasonic Pulse Velocity and Modulus of Elasticity

The results of *UPV* and E_{mod} values were given in Table 4.5 and Figure 4.10. Among the samples examined, the *UPV* values of synthetic-based finish coats, with a mean of 1167±175 m/s, seemed to be higher than cement-based undercoats, with a mean value of 847±147 m/s and one sample of cement-based finish coat, *FC5CB*,

with a value of 977±44 m/s. The synthetic-based finish coats *FC3SB*, *FC1SB* and *FC2SB* were found to have varying E_{mod} values of 1.36±0.02 GPa, 1.76±0.09 GPa and 2.89±0.78 GPa, respectively, while those of cement-based undercoats, $UC1CB_R$, $UC2CB_F$ and $UC3CB_T$, were found to be 1.30±0.13 GPa, 1.72±0.48 GPa and 0.86±0.12 GPa respectively. Parallel to *UPV* values, the E_{mod} values of synthetic-based finish coats seemed to be slightly higher than that of cement-based undercoats. The E_{mod} value of cement-based finish coat (*FC5CB*), 1.85±0.37GPa, was also determined to be within the range of synthetic-based finish coats.

Table 4.5. The results of *UPV* and E_{mod} values for finish coats and undercoats.

Sample	UPV (m/s)	E_{mod} (GPa)
FC3SB	1012±9	1.36±0.02
FC1SB	1134±28	1.76±0.09
FC2SB	1357±184	2.89±0.78
FC5CB	977±44	1.85±0.37
$UC3CB_T$	698±46	0.86±0.12
$UC1CB_R$	853±41	1.30±0.13
$UC2CB_F$	991±137	1.72±0.48

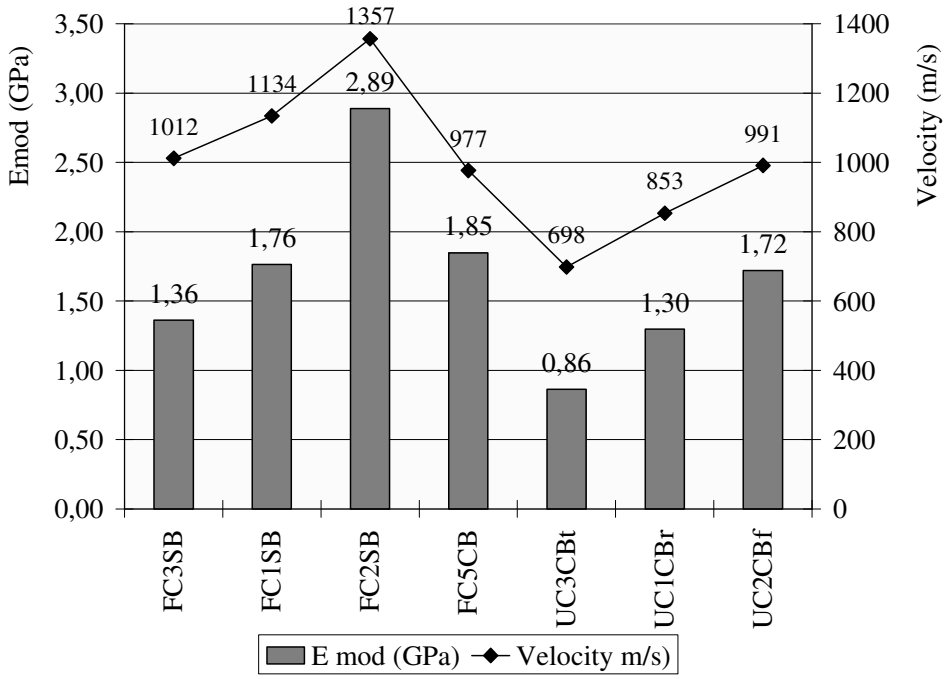


Figure 4.10. *UPV* and E_{mod} values for finish coats and undercoats.

The cement-based undercoat, $UC3CB_T$, which is directly applied on thermal insulation board to provide a subsurface for the finish coat, was found to have the lowest E_{mod} value of 0.86 GPa. It should be considered that its strength should be higher than this value due to its application together with reinforcing mesh. (Williams and Williams, 1994).

Except the synthetic finish coat, *FC2SB*, all coating layers used in the wall section appeared to have similar *UPV* and E_{mod} values which present continuity between the layers in terms of their strength.

CHAPTER 5

DISCUSSION AND CONCLUSION

In this chapter, experimental results are interpreted in terms of material properties of contemporary coatings used for insulated exterior walls, their compatibility in terms of water vapour permeability and modulus of elasticity and continuity of water vapour permeability along the wall section. At the end are given the conclusions followed by suggestions for future studies.

5.1 Evaluation of Some Physical Properties of Coatings

In this section, some physical properties of the samples are discussed with an emphasis on their water vapour permeability properties. In addition, they are compared with other contemporary and historical coatings/plasters.

Cement-based finish and undercoats were found to have the highest density and the lowest porosity and water absorption capacity (Table 4.1 and Figure 4.1). The synthetic-based finish coats had lower density and higher porosity and water absorption capacity than the cement-based coatings. The polymer-based ones, on the other hand were observed to have the lowest density and the highest porosity and water absorption capacity. The basic physical properties of the coatings seemed to have a relation with their material compositions. In addition, all coatings

except cement-based ones with high porosities were found to have high water absorption capacities varying in the range of 18±1.5% and 45±2.5%, while lower water absorption capacities were desirable.

Although water vapour diffusion resistance, μ values, of the finish coats, especially the acrylic polymer- and copolymer-based ones, were found to be high, all of them were found to be high water vapour permeable according to their S_D values below 0.14m and R_T values above 6 g/hm^2 (Table 4.2, Figure 4.2 and Figure 4.3) (TSE, 1999). Low S_D values were provided by the use of the finish coats in thin layers. In other words, the coats which had high resistance to water vapour permeation were determined to behave as high vapour permeable layers due to their application in thin layers.

Cement-based undercoats $UC2CB_F$, $UC1CB_R$ and $UC3CB_T$, on the other hand, were found to be medium permeable layers due to their S_D values in the range of 0.215±0.021m and 0.552±0.074m (TSE, 1999).

According to the permeance values given by Tye (1994), the finish coats, external paint and primer examined in this study were found to be more permeable than standard values accepted for the calculations. Parallel to this conclusion, when compared to the acceptable ranges of μ values given in literature for the calculation of condensation quantity (Pfeifer et al., 2001), all coats of this study seemed to have lower resistance to water vapour permeation.

On the contrary, when the S_D values of contemporary coats compared with the historic plasters, the historic ones seemed to have higher water vapour permeability than the contemporary ones (Esen, 2004; Caner, 2003; Akkuzugil, 1997).

5.2 Effect of Primer and Paint to the Permeability of the Finish Coat

The effect of primer and paint to the permeability of finish coats was determined by comparison of R_T and S_D values of primer, paint and finish coat individually and of finish coat with paint or primer (Figure 4.2, Figure 4.3 and ,Table 4.2). The S_D value of the synthetic-based primer *Pr1SB* was found to be 0.007±0.001m showing that it was a high water vapour permeable layer though it had a high μ value of 69.1±8.3. The results showed that the water vapour permeability of finish coats decreased in varying amounts when the primer was applied. For instance, by the application of primer layer, the highest increase in S_D values were observed at synthetic-based finish coats of *FC4SB* and *FC2SB* and made them medium permeable layers while this increase was negligible for other synthetic-based finish coats of *FC1SB* and *FC3S*. Such grouping was also observed in their basic physical properties. This indicated the existence of a relation between the interaction of primer to finish coats and the material composition of finish coats.

The S_D value of the acrylic copolymer-based exterior paint, *Pa1ACB*, was found to be 0.007±0.001m, showing that it was very water vapour permeable individually although it had a high μ value of 68.4±5.9. Similarly, to the effect of the primer, when the primer was applied on cement- based finish coat, *FC5CB*, the increase

in the total S_D value made the finishing layer medium permeable. This may be due to the fact that, the paint could have filled the pores of finish coat to a certain depth and caused to slow down the vapour flow from this intermediate layer between finish coat and paint.

5.3 Continuity of Water Vapour Permeability Along the Insulated External Wall Section

Acrylic copolymer-based *FC8ACB* and synthetic-based *FC3SB* together with the application of primer were found to be the most advantageous finishing system due to their high permeability (Table 4.2, Figure 4.2 and Figure 4.3). These layers with good breathing properties are desired in external walls in order to ensure that any water and/or water vapour entrapped underneath the finishing system are allowed to dry out from its exterior surfaces.

Water vapour transmission of each layer should be continuous along the wall section in certain ranges. The assessment of each layer, in this regard, was done by means of the combined interpretation of the results. The interpretations revealed that the continuity of water vapour transmission along the wall section was disturbed due to somewhat low and/or medium permeable layers such as thermal insulation layers and cement-based undercoats (Figures 4.4, 4.5, 4.6 and 4.7).

The charts showing the distribution of water vapour pressure as a function of S_D values of all layers along the wall section were evaluated both for

internally and externally insulated walls considering the assumptions of mean boundary conditions given in the standards (Figures 4.8 and 4.9). The results showed that there is no risk of condensation in between the layers of the externally and internally insulated walls. However, the charts showing the water vapour transmission rate and S_D values as a function of wall section in layers presented the location of critical zone where the vapour flow is interrupted and the interruption in quantitative basis. For instance, vapour transmission rate of 5cm thick *XPS* layer was found to be 90 times lower than the most permeable finish coat, *FC8ACB* while this ratio was 36 for *EPS* and 2 for rockwool layers of the same thicknesses. These results were also supported by S_D analyses. Among all layers, especially polystyrene-based thermal insulation boards, *XPS* and *EPS,* with S_D values of 6.858±0.111m and 2.714±0.152m, respectively, were found to interrupt water vapour flow considerably and, therefore, prevent the breathing capability of the masonry (Table 4.2, Figures 4.4 and 4.5). On the other hand, compared to XPS and EPS, rockwool was found to have very low μ value of 3.3±0.1 and a 5cm thick rockwool board was found to be medium permeable with an S_D value of 0.164±0.007m, close to the threshold of high permeability. Considering that thermal properties of the polystyrene- and mineral-based thermal insulation materials are similar, rockwool was found to be the most proper selection for the insulation of external walls and found to be suitable to be used with the water vapour permeable finish coats.

The comparison of the undercoating systems revealed that the undercoats $UC1CB_R$ and $UC2CB_F$ of externally insulated walls had lower water vapour permeability

values than the thermal insulation undercoat of externally insulated walls, $UC3CB_T$ (Tables 4.3 and 4.4). In this regard, the coating system of the externally insulated walls was found to be more advantageous than the coating system of the internally insulated ones.

It was observed that AAC had a very low resistance to water vapour permeation; even 6 times lower than that of the finish coats with the lowest resistance. When a unit thickness of AAC is considered, it was found to have good permeability property. For this reason, AAC masonry was found to be a suitable layer to be used together with the water vapour permeable finish coats, as it was so for the thermal insulation material, rockwool.

5.4 Compatibility of Finish Coats In Terms of Modulus of Elasticity

According to the results of mechanical properties, the coatings exhibited similar E_{mod} values with a mean value of 1.68±0.6 GPa except the finish coat *FC2SB* with the highest E_{mod} value of 2.89±0.78 GPa and the undercoat $UC3CB_T$ with the lowest E_{mod} value of 0.86 GPa. Since the undercoat $UC3CB_T$ was applied together with reinforcing mesh, it was expected to have a higher E_{mod} than the experimental result obtained (Williams and Williams, 1994).

The E_{mod} values of the coatings were compared with the experimental results found in the literature. The finish coats of the study were found to have considerably low E_{mod} values than the unmodified, latex- modified and polymer-impregnated

plasters studied by Çolak (2006). For instance, even the weakest plaster having an E_{mod} value of 4.0 GPa determined by Çolak (2006) was 1.4 times stronger than the synthetic-based finish coat *FC2SB*. Similar to this, the E_{mod} values of some cement-based plasters with additives determined by Andolsun et al. (2006) seemed to be two times higher than those examined in this study.

On the other hand, when compared with the mechanical properties of historical plasters, these coatings exhibited similar E_{mod} values to the historical mortars studied by Tuncoku (2001) and historical plasters studied by Caner (2003) and Esen et al. (2004). Even the historical ones were exposed to the weathering conditions for hundreds of years, they were still functioning. The ranges of their E_{mod} values were, therefore, assumed to be still enough to cope up with the weathering conditions. From this point of view, the E_{mod} values of finish coats seemed to have low but enough strength for their survival.

The E_{mod} values of the finish and undercoats and the masonry backing the finishing system were expected to be similar with each other in terms of the compatibility issue (Paulo et al., In Press; Caner, 2003; Tuncoku, 2001; Fabbri and Grossi, 2000; Sasse and Sneathlage, 1997). In addition, in multi layer systems, the elasticity of the layers should lower through exterior, but still by keeping enough strength. The results showed that, E_{mod} values of the finish coats, except the synthetic-based finish coat *FC2SB* with E_{mod} value of 2.89 GPa, seemed to have slightly lower strength than the masonry units, such as load bearing AAC units with 2.1 GPa (Andolsun et al., 2006). The smooth transition of the elasticity values from the masonry towards

exterior layers, which is desirable in terms of compatibility issue, was also observed. However, due to the highest E_{mod} value of *FC2SB*, some failures, such as cracks and flakes, may occur in a short period following its application.

5.5 Conclusion

By means of this study, the material properties of contemporary finish coats produced in Turkey were defined and differences between cement-based, synthetic-based and polymer-based finish coats, together with their complementary undercoats were determined in terms of some basic physical and mechanical properties.

The material properties of the synthetic-, cement- and polymer-based finish and undercoats varied in accordance with their material composition. In other words, coatings with similar physical properties seemed to correspond to similar material compositions. Such a relation was also observed between the material composition of coatings and the interaction of primer/paint with them.

In this regard, cement-based finish and undercoats were found to have the highest bulk density with the lowest porosity and water absorption capacity. Among non-cementitious finish coats, synthetic-based finish coats had higher bulk density and lower porosity than the polymer-based ones.

In terms of water vapour permeability characteristics, all finish coats studied were found to be high vapour permeable layers individually. Among these, it was observed that polymer-based finish coats were the most permeable materials, with lowest S_D values, in spite of their considerably high resistance to water vapour permeation, μ values. Although it is being cement-based, *FC5CB* was found to have good breathing property with low S_D value. Among the synthetic-based finish coats, *FC3SB* was found to be the most permeable.

All these high permeable finish coats were, in fact, found to have high resistance of water vapour permeation in a wide range, even reaching a considerably high μ value of 110±27.4 for the polymer-based finish coat, *FC7ACB*. High permeability of the finish layers was found to achieve by their conscious application in thin layers. During their application, elaborate workmanship is necessary since a special care should be taken to the coat thickness recommended by the firm, such as 3 mm for cement- and synthetic-based finish coats and 0.8 mm for polymer-based ones.

The water vapour permeability of finish coats were found to reduce in certain ranges due to the application of the primer and paint layers. It should be, therefore taken into account the total S_D of the finish coats together with their complementary coats. In this regard, the high permeable finishes *FC1SB*, *FC3SB*, *FC6APB*, *FC7ACB* and *FC8ACB* together with the primer application still remained as high permeable finishing systems. However, the application of primer made the finishes *FC2SB* and *FC4SB* medium water vapour permeable layers. Similarly, paint application made the cement-based finish coat *FC5CB* medium permeable. From

the point of water vapour permeability, the primer and paint seemed to be compatible only with some of the finish coats examined. The material properties of these primer and paint layer, therefore, should be improved for their proper combination with the other finish coats, especially for some synthetic- and polymer-based finish coats.

The use of complementary sub-layers, such as undercoats, is obligatory for the application of finishes. Two typical types of cement-based undercoat applications are commonly used in construction; first one is the thermal insulation undercoat $UC3CB_T$ used at externally insulated walls and the second one is the coating system consisting of rough and fine plasters $UC1CB_R$ and $UC2CB_F$ used at internally insulated walls. However, in contrast to finish coats, the cement-based undercoat systems were found to be medium permeable applications. Among these, the former one, thermal insulation undercoat, was found to be almost two times more permeable than the latter.

The application of permeable finishing systems is not enough to construct breathing walls. Such walls can be achieved only by the use of permeable layers along the wall section where a continuous vapour transmission provided in certain ranges. Thermal insulation board, which is the essential component of insulated walls to provide energy conservation and eliminate the risk of condensation in buildings, was found to be the main layer interrupting the water vapour flow along the wall section. It was concluded that *XPS* was the most inconvenient layer to be used in wall sections in terms of its very low vapour permeability. Similar to XPS, EPS was

also found to have very low vapour permeability. On the other hand, rockwool as the mineral-based thermal insulation material was found to be medium permeable due to its considerably low μ and S_D values compared to the polystyrene-based ones. As a result, among these three insulation material, rockwool seemed to be the most proper selection for the construction of breathing walls.

Externally insulated walls were found to be more permeable than internally insulated walls due to the use of more permeable undercoats. In addition, externally insulated walls were also found to have the low risk of condensation. In conclusion, walls insulated externally with rockwool boards and plastered with polymer-based finish coat, *FC8ACB* or synthetic-based finish coat *FC3SB*, were found to be the most proper combination in terms of breathing and thermal resistance capabilities.

All synthetic-based and cement-based finish coats and their complementary cement-based undercoats seemed to have sufficient strength when their E_{mod} values compared with those of historical plasters. Since the healthy relationships between the coating layers in terms of their E_{mod} values and their strength are still under discussion, this subject is not clearly defined yet. On the other hand, a similarity between the E_{mod} values of the coats and a hierarchy in these values lowering towards the exterior along the layers of wall section were found to exist. Considering these results, all coats examined in this study, except the synthetic-based finish coat, *FC2SB*, were thought to be suitable to be used together with each other and the masonry in terms of their E_{mod} values.

In order to determine the E_{mod} values of coats, it was not possible to prepare the samples in proper dimensions, especially for the polymer-based ones, as defined in the standards. Owing to this fact, it is necessary to improve the standard test methods in terms of sample preparation and/or determination of the modulus of elasticity for the layers applied in very thin layers.

Due to the similarities between the water vapour permeability properties and modulus of elasticity values of finish coats and AAC, finish coats seemed to be proper to be used with AAC masonry. However cementitious undercoats were found to be incompatible with AAC masonry due to their lower water vapour permeability.

Finally, the data obtained from this research was aimed to be a basis for the future researches on the physical, mechanical, compatibility and durability properties of the contemporary finish coats and for the compatibility properties of these finish coats with other contemporary and historical building materials. In addition to the water vapour permeability and modulus of elasticity properties, the other parameters of compatibility, such as thermal and moisture dilatation properties and water permeability should be examined in future studies. The relation between the resistance to water vapour permeation, μ value, and water permeability is another research topic which needs to be investigated in detail for the finish coats.

In construction, due to their lower cost, the polystyrene-based materials are commonly preferred for the insulation of buildings instead of more permeable

alternatives. However, there is a necessity to produce high permeable alternatives as thermal insulation materials, and then, to improve the breathing capability of insulated walls.

The methods using the graphs which show the water vapour transmission rate and S_D values as a function of layers forming the wall section were found to be useful to analyze the layers of a wall section and to find out the interfaces interrupting the vapour flow along the wall section.

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APPENDICES

APPENDIX A

EQUILIBRIUM WATER VAPOUR PRESSURE AT A GIVEN TEMPERATURE(İzocam, 2004; TSE, 1998)

	Saturated water vapour pressure (Pa)									
Temperature °C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
30	4244	4269	4294	4319	4344	4369	4394	4419	4445	4469
29	4006	4030	4053	4077	4101	4124	4148	4172	4196	4219
28	3781	3803	3826	3848	3871	3894	3916	3939	3961	3984
27	3566	3588	3609	3631	3652	3674	3695	3717	3793	3759
26	3362	3382	3403	3423	3443	3463	3484	3504	3525	3544
25	3169	3188	3208	3227	3246	3266	3284	3304	3324	3343
24	2985	3003	3021	3040	3059	3077	3095	3114	3132	3151
23	2810	2827	2845	2863	2880	2897	2915	2932	2950	2968
22	2645	2661	267ε	2695	2711	2727	2744	2761	2777	2794
21	2487	2504	2518	2535	2551	2566	2582	2598	2613	2629
20	2340	2354	2369	2384	2399	2413	2428	2443	2457	2473
19	2197	2212	2227	2241	2254	2268	2283	2297	2310	2324
18	2065	2079	2091	2105	2119	2132	2145	2158	2172	2185
17	1937	1950	1963	1976	1988	2001	2014	2027	2039	2052
16	1818	1830	1841	1854	1866	1878	1889	1901	1914	1926
15	1706	1717	1729	1739	1750	1762	1773	1784	1795	1806
14	1599	1610	1621	1631	1642	1653	1663	1674	1684	1695
13	1498	1508	1518	1528	1538	1548	1559	1569	1578	1588
12	1403	1413	1422	1431	1441	1451	1460	1470	1479	1488
11	1312	1321	1330	1340	1349	1358	1367	1375	1385	1394
10	1228	1237	1245	1254	1262	1270	1279	1287	1296	1304
9	1148	1156	1163	1171	1179	1187	1195	1203	1211	1218
8	1073	1081	1088	1096	1103	1110	1117	1125	1133	1140
7	1002	1008	1016	1023	1030	1038	1045	1052	1059	1066
6	935	942	949	955	961	968	975	982	988	995
5	872	878	884	890	896	902	907	913	919	925
4	813	819	825	831	837	843	849	854	861	866
3	759	765	770	776	781	787	793	798	803	808
2	705	710	716	721	727	732	737	743	748	753
1	657	662	667	672	677	682	687	691	696	700
0	611	616	621	626	630	635	640	645	648	653
-0	611	605	600	595	592	587	582	577	572	567
-1	562	557	552	547	543	538	534	531	527	522
-2	517	514	509	505	501	496	492	489	484	480
-3	476	472	468	464	461	456	452	448	444	440
-4	437	433	430	426	423	419	415	412	408	405
-5	401	398	395	391	388	385	382	379	375	372
-6	368	365	362	359	356	353	350	347	343	340
-7	337	336	333	330	327	324	321	318	315	312
-8	310	306	304	301	298	296	294	291	288	286
-9	284	281	279	276	274	272	269	267	264	262
-10	260	258	255	253	251	249	246	244	242	239
-11	237	235	233	231	229	228	226	224	221	219
-12	217	215	213	211	209	208	206	204	202	200
-13	198	197	195	193	191	190	188	186	184	182
-14	181	180	178	177	175	173	172	170	168	167
-15	165	164	162	161	159	158	157	155	153	152
-16	150	149	148	146	145	144	142	141	139	138
-17	137	136	135	133	132	131	129	128	127	126
-18	125	124	123	122	121	120	118	117	116	115
-19	114	113	112	111	110	109	107	106	105	104
-20	103	102	101	100	99	98	97	96	95	94

APPENDIX B

THERMAL CONDUCTIVITY COEFFICIENT OF THE MATERIALS EXAMINED IN THE STUDY (İzocam, 2004; TSE, 1998)

Building component	k_n: thermal conductivity coefficient of the material, W / m °C
Brick masonry	0.45
Expanded polystyrene (XPS)	0.04
Polymer-based finish coat	0.30
Cement-based plaster (under)coat	1.40
Internal plaster	0.87
Gypsum board	0.41

APPENDIX C

CODES, DESCRIPTIONS, TRADE MARKS AND NAMES OF THE SAMPLES.

Code	Description	Trade mark and name
FC1SB	Synthetic emulsion-based elastic finish coat with silicone additives	Kaleterasit-DekorPlus Exterior Plaster
FC2SB	Synthetic emulsion-based elastic finish coat with silicone additives	Kaleterasit-Grenart Exterior Plaster
FC3SB	Synthetic emulsion-based finish coat	Kaleterasit-Dekor Exterior Plaster
FC4SB	Synthetic emulsion-based finish coat	Kaleterasit-Pasifik Exterior Plaster
FC5CB	Cement-based finish coat	Kaleterasit-Minart Exterior Finish Coat
FC6APB	Acrylic polymer-based elastic finish coat containing silicone additives	Kaleterasit-Silikonateks Exterior Finish Coat
FC7ACB	Acrylic copolymer-based finish coat with silicone additives	Kaleterasit-Silikona Grenli Exterior Finish Coat
FC8ACB	Acrylic copolymer-based finish coat	Kaleterasit-Grena Grenli Exterior Finish Coat
$UC1CB_R$	Cement-based rough plaster	Prepared in the laboratory
$UC2CB_F$	Cement-based fine plaster	Prepared in the laboratory
$UC3CB_{Ti}$	Cement-based thermal insulation plaster	Kaleterasit-Kaleplast Undercoat Plaster
Pr1SB	Synthetic emulsion-based primer	Kalekim-Uniastar
Ti1XPS	Extruded polystyrene	İzocam- External Insulation Extruded Polystyrene Foamboard 1500
Ti2EPS	Expanded polystyrene	İzocam-External Insulation Expanded Polystyrene
Ti3RW	Rockwool	İzocam- External Insulation Rockwool
Pa1ACB	Acrylic copolymer-based exterior paint	Kalekim-Grena Exterior Paint