Energy Education Science and Technology Part A: Energy Science and Research
2013 Volume (issues) **31(1):** 79-86

Air leakage measurement and analysis in duct type heating/cooling coils

Hatice Canbaz[1], Engin Söylemez[1], Ayhan Onat[2,*]

[1]*Friterm Termik Cihazlar San. ve Tic. A.S., 34957 Tuzla-Istanbul, Turkey*
[2]*Marmara University, Technical Education Faculty, Energy Department, 34722 Istanbul, Turkey*

Received: 20 August 2012; accepted: 12 December 2012

Abstract

The primary purpose of this study is to investigate the sources and rates of the air leakages in duct type heating cooling coils (DTHCC). In order to figure out the rate of air leakages in DTHCC, the tests have been primarily carried out on the reference duct type heating cooling coil (RDTHCC) as well as that, the RDTHCC has been tested on which the given enhancements have been implemented in the same order as follows: (1) only the corner's of RDTHCC have been sealed with a sealant, (2) only a rubber has been applied to the zones where casings and end-plates are joint and finally, (3) third step in which both enhancements are applied together. In this study, for the average test pressure of 400, 800, 1200, 1600, and 2000 Pa, air leakage rates of enhanced coils have been calculated and compared with the RDTHCC test results. Considering the maximum test pressure of 2000 Pa, the highest decrease in leakages can be seen with a 77,97% in the application where both enhancements carried out together, whereas the lowest decrease can be seen with a 26,07% in the enhancement step of only the corner's of RDTHCC have been sealed with a sealant. When only a rubber applied to the joints, the reduction is significant with a level of 62,56 %.

*Keywords***:** Heating coil; Cooling coil; Duct type; Air leakage; DTHCC
©Sila Science. All Rights Reserved.

1. Introduction

Any study and research of an air conditioning system applied to residential, commercial and industrial buildings should be focused mainly on energy losses contributed by the air leakages in addition to indoor air quality, thermal comfort, sustainability and environmental protection [1]. There are a wide range of components which constitute a central heating, ventilating and air conditioning (HVAC) duct system that is a branching network of circular, rectangular and elliptical (oval) tubes produced from sheet metal, fiberglass board or a

[*]Corresponding author. Tel.: +90-532-644-6598 or +90-216-336-5770; fax: +90-216-337-8987.
E-mail address: onattayhan@gmail.com (A. Onat).

flexible plastic and wire composite. These components are dampers, turning vanes, variable-air-volume (VAV) control units, DTHCC, supply and return registers and sensors for temperature, humidity, smoke, carbon dioxide concentration, pressure and flow rate [2]. In various investigations and studies, it is highlighted that energy loss due to the air leakage in air handling unit's (AHU) and ducts is at a considerable level.

The duct systems used especially in office, large commercial and industrial buildings and dwellings leak air substantially owing to inadequate ductwork and ill-fitted components, insufficient sealing work, worn tapes and physical damage during maintenance, etc [3]. Although air leakage is a serious problem in ducts, the necessity of decreasing leakages is not really realized commonly. The redundant energy use related to the air leakage occurs with the need for extra air supplied by fan so as to recover the amount of air leaked. An increase in leakages leads to an increase in fan load, thus fan power consumption [4]. Liddament et al. [3] have investigated the implication of duct leakage; a field study was performed on 42 duct systems in Belgium and France. Their study shows that the air leakage rate appears to be typically three times greater than the maximum air leakage limit highlighted in EUROVENT 2 (Class A). Ozerdem et al. [2] have analyzed the effect of air leakage on energy wastage. In their experiments it is indicated that the leakage from the joint surfaces and corners, up to 92% for circular and 86% for rectangular ducts, has the highest share in total air leakage. In addition, seam leakage has also a significant share in total leakages with up to 13% for circular and 20% for rectangular ducts. One solution has been suggested to decrease leakages is using sealing gaskets. Fisk et al. [4] investigated air leakages of duct systems in large commercial buildings. In their research, it is underlined that the energy losses of ducts are triggered by both air leakage and conduction. In addition to this, the estimated air leakage rates in supply duct systems as a percentage of the inlet air flow rate are in the range of 0% to 30%.

There are several standards determining air leakage limits and classes of air handling units (AHU) and ducts such as Eurovent 2/2, EN 1886 and DW/143 (ductwork leakage testing), EN 1751, SMACNA and EN 15727:2010. All of these standards force to systems to avoid further costs, power waste and noise problem because of air leakage. To structure the framework of this experimental investigation, some important studies on air leakages in ductworks have been examined closely due to the fact that duct type heating-cooling coils have common behaviors in terms of air wastage with the ductworks.

The DTHCCs which enable the conditioning of different zones and flexibility in application in buildings are generally employed in compact and central station AHU. To meet the required extra capacity in various processes, they are also used as heating or cooling devices. With the application of these coils to high energy efficient heat recovery systems, the entire system becomes more compact as well as that it avoids occupation of large spaces. Besides, they can be applied to Variable Air Volume (VAV) systems used for conditioning of hospitals, shopping centers and convention facilities. In these VAV systems, the air is conditioned at a given level and is carried to the conditioned space. Before entering the space, the conditioned air reaches its final conditions by means of a flow regulating device (VAV box) and duct type coil. They are therefore not only increase energy efficiency but also prevent energy losses over long ducts. Depending upon refrigerant, heating/cooling coils; direct expansion duct type DX coil, condenser and steam coils are available. In terms of duct connection geometry, they are classified as rectangular and circular type coils.

Air leakage in DTHCC accepted as part of duct works have not seriously been investigated so far and their leakage limits have been evaluating within the scope of ducts' air leakage standards mentioned above. It has recently been realized that the air leakage of coils must be

taken into account in spite of having less surface area compared to ductworks' area. DTHCCs manufacturing companies are now required to not only decrease leakage rates below the levels determined in the standards but also build test rigs which meet the requirements of standards and certify air leakage testing procedures.

2. Materials and methods

2. 1. Materials

2. 1. 1. Orifice plate air leakage test rig

Proctor et al. [5] and Srinivasan [6] indicated that various methods of testing have been used in order to measure the air leakages in ducts. Srinivasan [6] also suggested that the most accurate and sensitive method of air leakage measurement is the orifice method. So as to measure air leakages for the purpose of scientific research and define acceptable values in the standards in air leakages of ducts, orifice plate method is widely used. Orifice plates which have a fixed geometry are also the most popular flow meters in fluid flow measurement especially in oil and gas industry. Being simple, easy to produce and having high accuracy advantage them against their competitors [7].

Because it proved qualitative way of testing, orifice flow method has been chosen for the air leakage measurement of coils. Air leakage test rig is established in reference to SMACNA (HVAC Air Duct Leakage Test Manual). For calculation of mass flow and pressure drop measurement method EN 1886, EN 15727:2010 are considered as well as SMACNA [8], [9], [10], [11]. According to the standards of EN 15727:2010 and DW 144, each test pressure must be kept within ±5 % of the specified test pressure at least for 5 min. Besides, in this research, this rate has been tried to maintained ±2 % as much as possible, because the effect of the test pressure corresponding to this estimate is nearly zero.

The basic components used in the test system are variable speed blower, potentiometer, stainless steel tube, flow straightener (in the tube), orifice plate, flexible hose, and pressure and differential pressure transmitters as shown in Fig. 1. The blower has a max air flow of 230 m^3/h, max pressure increase of 3500 Pa, max power input of 190 W, max speed of 9000 min^{-1}. The pressure transmitter has a pressure range of between 0 and 3000 Pa. Its accuracy is ±1 % when the pressure is above 250 Pa. If the pressure is lower than 250 Pa, the accuracy is ±2 %. In the system, there are two differential pressure transmitters. One of them is for the low pressure (0-100 Pa) measurements which enable to collect more accurate values; the other one is for the high pressure applications (0-1250 Pa). Both have an accuracy of ±1 %.

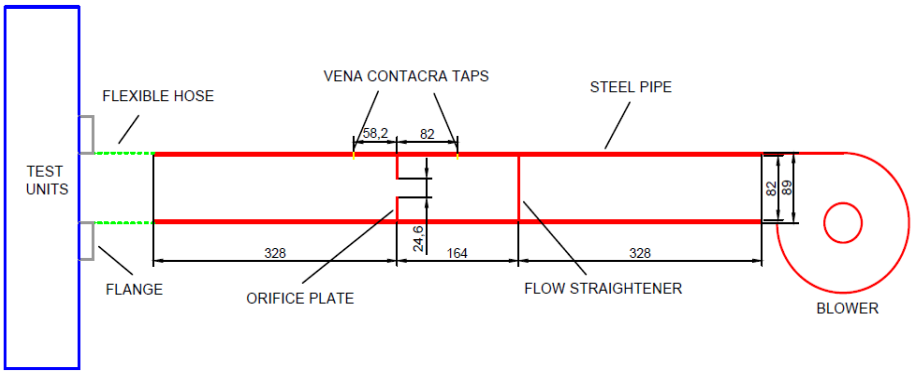
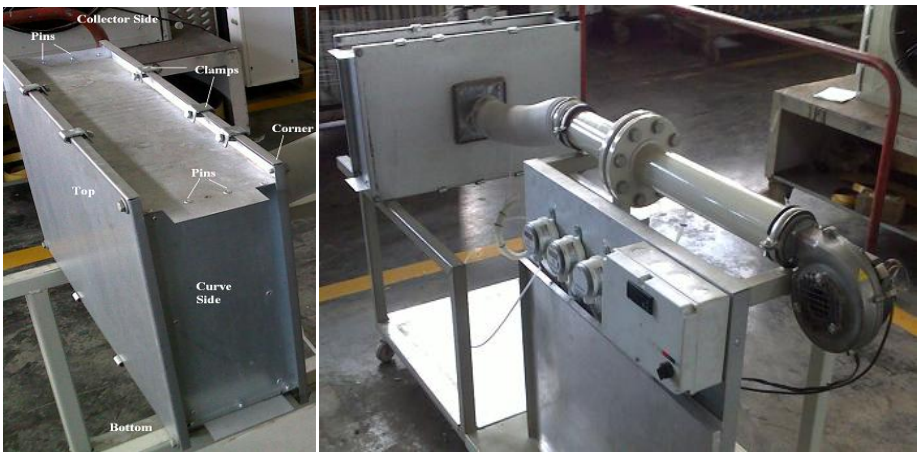


Fig. 1. Drawing of the test rig.

2. 1. 2. The tested RDTHCC

The RDTHCC is made from galvanic. Its length (L) is 700mm, height is 400, and width is 190mm. It has also a thickness of 1mm. The inner surface of the unit is calculated as 0,4256 m^2. As far as the joints of the unit are concerned, both bottom and top of the unit on the collector side have 4 pins. The distance between the pins (pin spacing) is 50 mm while the distance between the pins and edges (corners) is 20mm. On the curve side, there are 3 pins on the top side. Pin spacing and pin-edge spacing are 75 mm and 20 mm, respectively. For the bottom of curve side, the dimensions are exactly same with that of collector side. The tested coil and test rig connection is shown Fig. 2.



1. Fig. 2. The tested coil and test rig connection.

2. 2. Methods

For the purpose of this investigation, it has been made sure that no leakages occur in the other parts of the RDTHCC, because the air leakages from the corners and casing-end plate joints are only considered in this paper. One of the air leakage zones is the holes seen between the tubes and end-plates. To prevent leakages from these holes, the RDTHCC has been produced without tubes. The enhancements done on the RDTHCC are as following:

1. To decrease the leakages from the corners of the RDTHCC, the corners have been sealed with multipurpose sealant (SikaFlex-221 Grey).
2. To decrease the leakages from the zones where casings and end-plates are joint, a rubber seal have been used.
3. As final enhancement stage, both enhancements described above are applied together.

In calculation of the volume flow, the test measurement method is accepted as airflow across a sharp edge-orifice with reference to SMACNA. At the sea level and 20 ^oC temperatures, the formula is in British Imperial units,

$$Q=21.8xKxD_2^2x\sqrt{\Delta P} \quad [cfm] \qquad [1]$$

The Eq. 1 is converted to the metric system as

$$Q = 21.8 \times K \times \left(\frac{D_2}{25.4}\right)^2 \times \sqrt{\frac{\Delta P}{(10\times 25.4)}} \times 1.699 \quad \left[\frac{m^3}{h}\right] \qquad [2]$$

Q is volume flow (m^3/h), K is orifice coefficient (for this test rig, D_2/D_1= 0,3, hence K=0,6) (EN 15727:2010), D_1 and D_2 inner diameter of the tube and orifice diameter (m), respectively. D_1 is 82 mm while D_2 is 24.6 mm. In concern with test procedure, firstly, pressure drop (ΔP, Pa) at a specified test pressure (P_{test}, Pa) is measured, then volume flow of air (Q) is calculated by means of the Eq. 2. To calculate air leakage limit of DTHCC:

$f = Q/A \quad [L/sm^2]$ [3]

f (ALL) is air leakage limit (l/sm^2), Q is mass flow converted to L/s. A is area of coil inner surface (m^2). Air leakage limit is calculated by means of the Eq. 3. Decrease in leakages and error margin as percentage (%) are calculated as:

$$\text{Decrease in air leakages (\%)} = [(ALL_{RDTHCC}-ALL_{DTHCC})/ALL_{RDTHCC}]*100 \quad [4]$$

$$\text{Error margin (\%)} = [(DTHCCTP-RDTHCCTP)/RDTHCCTP]*100 \quad [5]$$

where DTHCCTP is the test pressure of DTHCC and RDTHCCTP is RDTHCC's test pressure.

2. Test results and discussions

In DTHCCs, the air mostly leaks from the corners, casing-end plate joints, pins/rivets, and the tube- end plate joints. In this study, the amount of leakages from the corners and casing-end plate joints are only investigated. The positive pressure in the coil, as regards applications and standards, changes between 400 and 2000 Pa. Hence, the tests have been performed at five different pressures, 400, 800, 1200, 1600, and 2000 Pa for the RDTHCC and each enhancement steps. The amount of leakages, decrease in leakages, and error rates are also calculated. The test results show that when the air pressure inside the coil increases, the rate of the leakages also increases.

The first enhancement step's test results compared to that of RDTHCC can be seen from the Table 1 and Fig. 3. The RDTHCC 's corners have been sealed with a sealant. The lowest reduction in leakages has been provided with this enhancement. According to the results of the RDTHCC tests, the amount of the leakages at 410,92 Pa and 2019,43 Pa are 0,751 and 2,174 L/m^2s, respectively. After the sealant is applied to the corners, at the test pressure of 408,06 Pa, the leakage amount is 0,649 L/m^2s, whereas the leakage is 1,607 L/m^2s at 2012,99 Pa. The decrease rate in leakages at 408,06 Pa is 13,53%, while at 2012,99 Pa, it is 26,07%. There is not a considerable change in decrease rate with the increasing air pressure in the coil. At 800 Pa test pressure, the decrease rate is 20,09 and the amount of leakages is 1,25 times less than that of RDTHCC.

Table 1. The first enhancement step's test results compared to that of RDTHCC. The RDTHCC's corners have been sealed with a sealant.

Test No	RDTHCC/ DTHCC inner surface area (m^2)	Reference product-no enhancements				Enhancement with only sealant				Decrease in the air leakage limit (%)	Error margin at the test pressure (%)
		RDTHCC test pressure	Orifice pressure drop	Volume flow rate	Air leakage limit	DTHCC test pressure	Orifice pressure drop	Volume flow rate	Air leakage limit		
		(Pa)	(Pa)	(L/s)	(L/m^2s)	(Pa)	(Pa)	(L/s)	(L/m^2s)		
1	0,426	410,92	0,774	0,32	0,751	408,060	0,579	0,276	0,649	13,53%	-0,70%
2	0,426	814,88	1,893	0,5	1,175	800,933	1,210	0,400	0,939	20,09%	-1,71%
3	0,426	1235,78	3,039	0,633	1,488	1205,483	1,808	0,488	1,148	22,87%	-2,45%
4	0,426	1638,45	4,686	0,786	1,848	1608,733	2,805	0,608	1,430	22,63%	-1,81%
5	0,426	2019,43	6,484	0,925	2,174	2012,994	3,545	0,684	1,607	26,07%	-0,32%

To eliminate the leakages from the where casings and end-plates are joint together, a rubber seal have been used. The Table 2 and Fig. 4 represents that sealing with a rubber has a

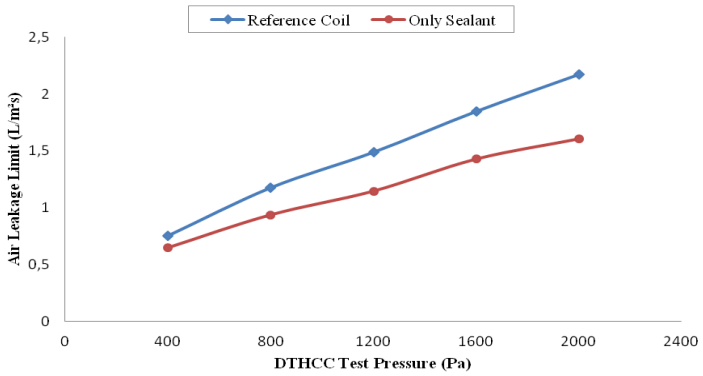


Fig. 3. RDTHCC's results and the enhancement with only sealant.

significant effect on lessening the leakages. At the test pressure of 406,29 Pa, the leakage amount and decrease rate are 0,398 L/m^{2}s and 47%, respectively. Regarding to the pressure of 2005,57 Pa, the leakage amount is 0,814 L/m2s that is equal to a 62,56% reduction. It is clear that with the increasing of the test pressure, the enhancement rates are also increased. However, the enhancement rate is almost same for the pressures of 1200, 1600 and 2000 Pa. The decrease in leakages at 800 Pa is just above %55 which means the amount of the saved air is 2,25 times higher than that of RDTHCC.

Table 2. RDTHCC 's results and the enhancement with only rubber. To eliminate the leakages from the where casings and end-plates are joint together, a rubber seal have been used.

Test No	RDTHCC/ DTHCC inner surface area (m²)	Reference product-no enhancements				Enhancement with only rubber				Air leakage decrease (%)	Error margin in RDTHCC /DTHCC test pressure
		RDTHCC test pressure	Orifice pressure drop	Volume flow rate	Air leakage limit	DTHCC test pressure	Orifice pressure drop	Volume flow rate	Air leakage limit		
		(Pa)	(Pa)	(L/s)	(L/m^{2}s)	(Pa)	(Pa)	(L/s)	(L/m^{2}s)		
1	0,426	410,92	0,774	0,32	0,751	406,29	0,217	0,169	0,398	47,00%	-1,13%
2	0,426	814,88	1,893	0,5	1,175	806,69	0,374	0,222	0,522	55,57%	-1,01%
3	0,426	1235,78	3,039	0,633	1,488	1220,81	0,463	0,247	0,581	60,95%	-1,21%
4	0,426	1638,45	4,686	0,786	1,848	1617,2	0,739	0,312	0,734	60,28%	-1,30%
5	0,426	2019,43	6,484	0,925	2,174	2005,57	0,909	0,346	0,814	62,56%	-0,69%

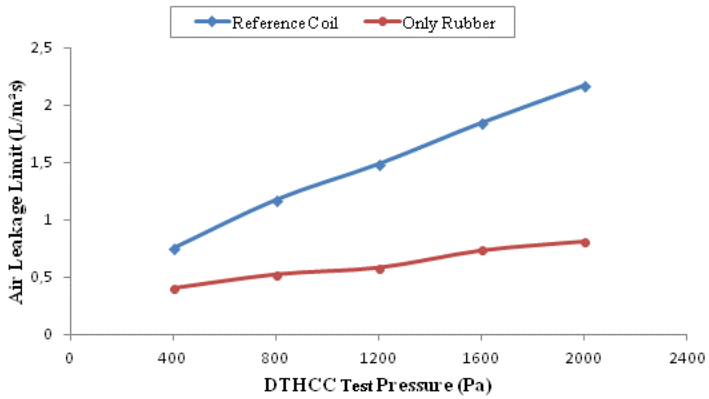


Fig. 4. RDTHCC's results and the enhancement with only rubber.

In this final enhancement, the first two enhancements are applied to the **RDTHCC**, represented in Table 3 and Fig. 5. At 404,34 and 2002,38 Pa, the amount of the leakages are 0,211 L/m^{2}s and 0,479 L/m^{2}s, respectively. The decrease rate is 71,90% for the 404,34 Pa and 77,96% for the pressure of 2002,38 Pa. At 800 Pa, decrease rate is 73%, 3.75 times less air is consumed. There is a slight rise in decrease rate with the increasing pressure.

Table 3. Enhancement with sealant and rubber. In this final enhancement, first two enhancements are applied to the RDTHCC

Test No	RDTHCC/ DTHCC inner surface area (m²)	Reference product-no enhancements				Enhancement with both rubber and sealant				Air leakage decrease (%)	Error margin in RDTHCC /DTHCC test pressure
		RDTHCC test pressure (Pa)	Orifice pressure drop (Pa)	Volume flow rate (L/s)	Air leakage limit (L/m^{2}s)	DTHCC test pressure (Pa)	Orifice pressure drop (Pa)	Volume flow rate (L/s)	Air leakage limit (L/m^{2}s)		
1	0,426	410,92	0,774	0,32	0,751	404,34	0,061	0,09	0,211	71,90%	-1,60%
2	0,426	814,88	1,893	0,5	1,175	804,22	0,137	0,134	0,315	73,19%	-1,31%
3	0,426	1235,78	3,039	0,633	1,488	1204,73	0,217	0,169	0,397	73,32%	-2,51%
4	0,426	1638,45	4,686	0,786	1,848	1612,99	0,265	0,187	0,44	76,19%	-1,55%
5	0,426	2019,43	6,484	0,925	2,174	2002,38	0,315	0,204	0,479	77,97%	-0,84%

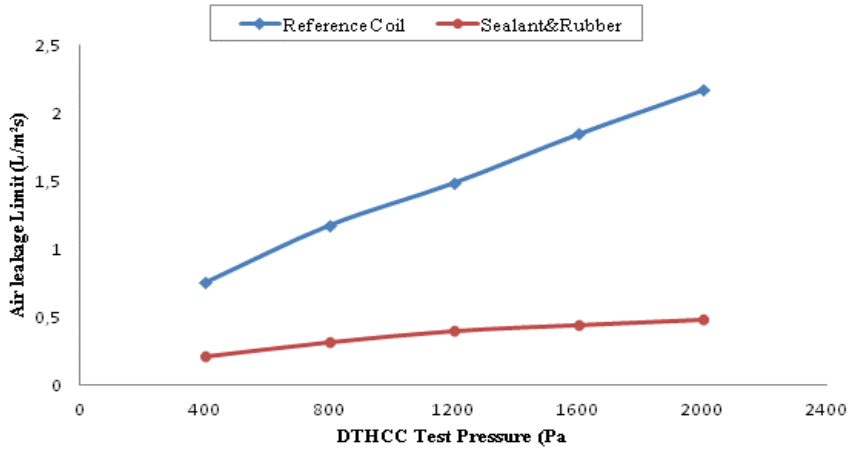


Fig. 5. RDTHCC's results and the enhancement with sealant and rubber.

3. Conclusions

The factors trigger the air leakages in DTHCC have been investigated and an experimental study is carried out to measure and calculate the amount of leakages. To do this, the testings have been performed on the RDTHCC at different test pressures. Initially, the RDTHCC is tested without any enhancements on it, then it has been tested on which the given enhancements have been implemented in the same order as follows: (1) only the corner's of RDTHCC have been sealed with a sealant, (2) only a rubber has been applied to the zones where casings and end-plates are joint and finally, third step (3) in which both enhancements are applied together. For the average test pressure of 400, 800, 1200, 1600, and 2000 Pa, the results of enhancements, with an error of 2,51%, have been calculated and compared with the RDTHCC test results.

1. The first enhancement, the RDTHCC's corners have been sealed with a sealant. The lowest reduction in leakages has been provided with this enhancement. After the sealant is applied to the corners, at the test pressure of 408,06 Pa, the leakage amount is 0,649 L/m^{2}s, whereas the leakage is 1,607 L/m^{2}s at 2012,99 Pa. The decrease rate in leakages at 408,06 Pa is 13,53%, while at 2012,99 Pa, it is 26,07%. There is not a considerable change in decrease rate with the increasing air pressure in the coil.
2. To eliminate the leakages from the where casings and end-plates are joint together, a rubber seal have been used. At the test pressure of 406,29 Pa, the leakage amount and decrease rate are 0,398 L/m^{2}s and 47%, respectively. Regarding to the pressure of 2005,57 Pa, the leakage amount is 0,814 L/m^{2}s that is equal to a 62,56% reduction. It is clear that with the increasing of the test pressure, the enhancement rates are also increased. However, the enhancement rate is almost same for the pressures of 1200, 1600, and 2000 Pa.
3. In the final enhancement, first two enhancements are applied to the RDTHCC. The highest reduction in leakages has been provided with this enhancement. At 404,34 and 2002,38 Pa, the amount of the leakages are 0,211 L/m^{2}s and 0,479 L/m^{2}s, respectively. The decrease rate is 71,90% for the 404,34 Pa and 77,96% for the pressure of 2002,38 Pa. There is a slight rise in decrease rate with the increasing pressure.
4. It has been discovered that there has been no experiment conducted the DTHCCs; thus, naturally there is no standard defining the air leakage classes of the DTHCCs. The classification of the air leakage limits is being made according to standards defined for ductworks and AHUs. Due to the particularly having very less area in comparison with the duct systems, it is irrelevant to determine their leakage classes based upon current standards for duct systems.

Acknowledgements

We would like to thank the Friterm AŞ for their support in establishing the test system and their inspiration on the development of this study.

References

[1] Herman U, Kelly B, Price H. Review on thermal energy storage with phase change; materials, heat transfer, analysis and applications. Applied Thermal Eng 2003:23:251-83.
[2] Aydin Ç, Özerdem B. Air leakage measurement and analysis in duct systems. Energy Build 2006;38:207-213.
[3] Carrie FR, Bossaer A, Andersson JV, Wouters P, Liddament M. Duct leakage in european buildings: Status and perspectives. Energy Build 2000;32:235-243.
[4] William J, Fisk WD. Duct systems in large commercial buildings; physical characterization, air leakage, and heat conduction gains. Energy Build 2000;32:109-119.
[5] Proctor JMB. Diagnosing Ducts. Home Energy Magazine Online, 1993.
[6] Srinivasan K. Measurement of air leakage in air-handling units and air conditioning ducts. Energy Build 2005;37:273-277.
[7] Beck S, Mazille J. A study of a pressure differantial flow meter that is insensitive to inlet conditions. Flow Measur Instrument 2002;165:379-384.
[8] DW/143, H. Ductwork Leakage Testing, 2000.
[9] EN1886 Ventilation for Buildings-Air Handling Units-Mechanical Performance, 2003.
[10] Eurovent2/2. Air Leakage Rate in Sheet Metal. Air Distribution Systems. 1996.
[11] SMACNA, HVAC Air Duct Leakage Test Manual,1985.