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# The performance evaluation of the modular design of hybrid wall with surface heating and cooling system

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**Abstract**

Reducing the use of mechanical heating and cooling systems in buildings, which accounts for approximately 30-40% of total energy consumption in the world, has a major impact on energy conservation. Considering the formation of buildings that have sustainable and low energy utilization, structural elements as well as mechanical systems should be evaluated with a holistic approach. From this point of view, in this study it is proposed that wall elements, which are vertical building elements, and constitute a broad area within the structure, are regulated with a different system concerning the reduction of building energy consumption ratio. Within the scope of this study, integration of modular wall elements with surface heating and cooling system which are convenient for using hybrid energy, into the buildings will be evaluated.

One of the aims of the study is to determine the direct impact of the product on architectural design process and identify the issues that will affect the process, and need to be resolved. In design, implementation and usage phases, integration of technical combination and montage details of modular wall elements, together with issues regarding energy saving, heat-saving, and other environmental aspects will be discussed in detail.

As a result, the ready-wall product with surface heating and cooling modules will be created and defined as hybrid wall and will be compared with the conventional system in terms of thermal comfort. After preliminary architectural evaluations, certain decisions that will affect whole architectural design processes (pre and post design) such as the performance in implementation and use, maintenance, lifetime, and renewal processes will be evaluated in the results.

**Keywords**
Architectural design, Energy saving, Hybrid, Modular ready-wall element, Thermal comfort.

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## 1. Introduction

Reducing the use of mechanical heating-cooling systems which is a great part of the energy consumption in buildings has a significant impact on energy conversation. Considering the formation of buildings that have sustainable and low energy utilization, structural elements as well as mechanical systems should be evaluated with a holistic approach. From this point of view, in this study it is proposed that wall elements, which are vertical building elements and constitute a broad area within the structure, are regulated with a different system concerning the reduction of building energy consumption ratio. Within the scope of this study, integration of modular wall elements with surface heating and cooling system which are convenient for using hybrid energy, into the buildings will be evaluated.

This study was compiled from the predesign studies of the project conducted within the scope of San-Tez project coded under 0462.STZ.2013-2. In the ongoing project, studies are continued to detail the modular hybrid wall product architecturally and mechanically and accommodate it for the use in buildings.

## 2. Modular hybrid wall elements

In the design of ready-wall elements, the stages of

- Setting certain standard and sizes in terms of architectural design,
- Detailing of the wall element according to its area (internal partition wall, external wall),
- Solution of junction points,
- Obtaining surfaces suitable for the building from the aspects of both design and structure

will be deliberated to create those elements (Göçer, Işık, 2007).

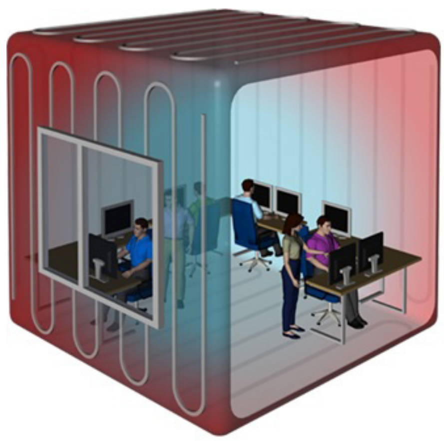

***Figure 1.*** *Surface heating-cooling systems (Koca et al, 2014).*

The advantages of surface heating-cooling systems include increasing comfort, energy efficiency and being eco-friendly, comfortable and flexible design, low operating and zero maintenance costs, and quiet operation and rapid installation.

Named as radiant systems, the working principle of these systems is that they do not interact with air in the space but with the users and equipment directly. When in heating mode, the heat on the heated surface transmits onto cold surfaces (people, furniture) by radiation.

### 2.1. Design criteria

An architectural design process begins with the schematic design phase, continues with the development of the design and ends with production-application phase. These phases affect each other; there is a cycle, an interaction that occurs between the processes. During the schematic design phase, different design alternatives can be produced by gathering all information on the building together. Gathering the product information and the properties of the building constitute the design strategy of the project. It is necessary to try and decide many options during the design development. Furthermore, the results to be obtained from the practice need to be estimated beforehand. The post-application feedback is needed for the application of new technologies. It is important to know the details on performance, maintenance, lifecycle and renovation processes in practice and usage, and all these details have an impact on the architectural design.

As a result of the design decisions, modular hybrid wall modules provide benefits to building users, investors and designer-practitioners. Because there is no fan noise, quiet operation is provided. Low air movements enable the building to provide comfortable conditions for users. The placement of mechanical system in the panels by taking into consideration combinations aims to obtain clean and hygienic designs.

With regard to the benefits for the investors, availability of the heating and cooling mechanism in a single system and small channels reduces the surface area of the panels. Moreover, thanks to production module planning, panels with low operation and zero maintenance costs can be produced. Panel-scale channel connections, availability of inspection and montage hatches for each panel and modularity of the panels allow for fast and reliable assembly.

Smaller surface area coverage offers more creative and continuous design opportunity to the designers and assemblers. Being suitable for any type of building (new and renovated) makes it more easily marketable and preferred more.

The design and use flexibility feature provides more advantages compared to the wall elements created with conventional systems. Its modularity, making mold design and production easier and possibility of using the same mold for the production of different size of elements enable the design process to be easier. Its form, dimension and weight not increasing transportation costs will ensure easy construction and low costs. Thanks to its modularity feature, plastering (especially on the outer façade) and scaffolding are not needed, which can be considered as an additional contribution to the construction process. Fast assembly decreases workmanship costs and project completion time.

## 2.2. Structural criteria

The resistance of the product to different levels of force, shape constancy and resistance are of significant factors that should be taken into consideration in the creation of the ready-wall element cross-section and structural design planning. Easily processable and achievable dimensions that optimally comply with the performance-cost parameter should be used in all ready-wall alternatives. Parameters such as restrictions by zoning regulations, structural function, carrier system, axis ranges should be taken into consideration for certain standardization for the building function and construction systems where the wall element will be used.

The most importance structural criterion is that the panels should ensure minimum connection and insulated jointing. The panel width should be determined according to the spaces on the buildings to ensure that dimensional deviations do not cause any difficulty when assembling.

Providing sufficient strength and impermeability of the alternative cross-sections combination system and materials used in the building envelope to allow for thermal movement, have sufficient thermal conductivity resistance should be planned in terms of improving the thermal comfort.

No thermal bridges should be established either within the panel or on joints to ensure that the thermal comfort conditions stay within the desired values in the space.

Variables that should be taken into consideration in the design of the modular hybrid wall installation are as follows:

- Heating and cooling pipe arrangement, distance between pipes, desired flow rate, pipe diameter,
- Determining heat fluxes of the sur-

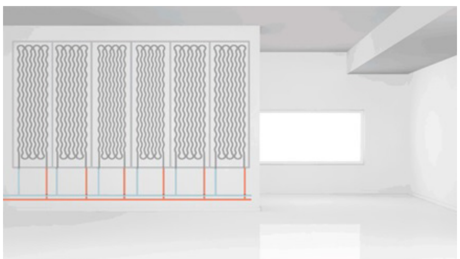

***Figure 2.*** *Schematic hybrid ready-wall element (Koca et al, 2014).*

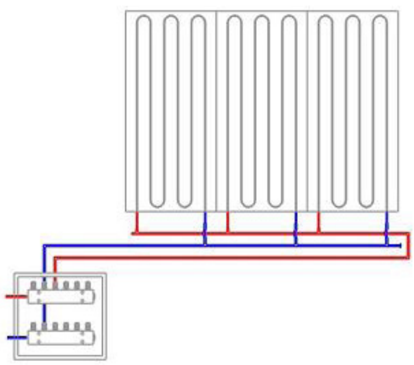

***Figure 3.*** *Modular hybrid wall installation design (Koca et al, 2014).*

face heating and cooling system based on the building heating and cooling loads,
- Suitability of the installation distribution system.

### 2.3. Performance criteria

In terms of performance, the product is expected to be used by deciding on the alternative material to be used on the structure surface to provide effective heating - cooling with the integration of surface heating and cooling system to the hybrid structure and improving thermal comfort conditions in the space. The building product will increase the performance by creating a lighter product compared to other wall implementations. Developing a hybrid ready-wall product with heating and cooling system instead of wall systems created with other structural elements such as bricks etc. will ensure faster and easier implementation.

## 3. Hybrid wall element studies and evaluation

This study uses the experimental results of the project coded under TEYDEB 3100577 and supported by the Scientific and Technological Research Council of Turkey (Tübitak). A test room was created to perform analyses and measurements within the scope of this previous project. The test room had five different volumes as follows: ceiling (volume 1), internal volume (volume 2), external volume (volume 3), floor (volume 4) and working volume (volume 5). The walls of the test room with a surface area of 24 $m^2$ (6mx4m) were 3 meters in height.

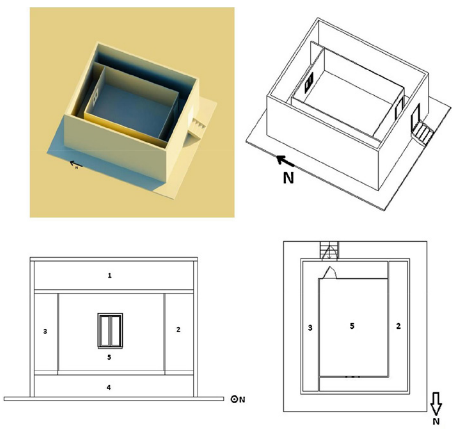


***Figure 4.*** *Photos of test room (TSE 825, 2008).*

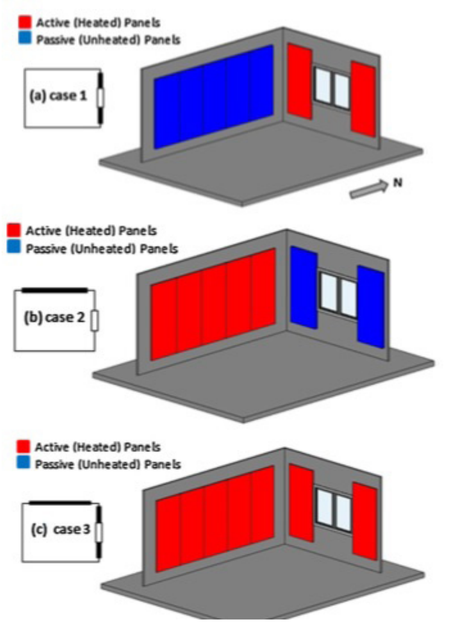


***Figure 5.*** *Radiant heating wall panel arrangement (TSE 825, 2008).*

Thermal transmittance coefficient of the walls was determined according to TSE 825 standards (Provisions, 2007). The window on the northern wall in the test room facing the external volume has double-glass (TSE 825, 2008).

Radiant panels were placed on wall surfaces with three different working volumes to create test rooms. Analyses were made on seven different heat values between the range of 30 and 42°C on the hot water distributed from the main hydraulic system for each condition.

According to the test results, panel heating was more dominant compared to conduction heating. Panel heating transfer rate is 68% in average. Different configurations of the radiant wall systems affect the panel heating transfer by around 10% on all sample test setups. However, each alternative arrangement affects the conduction heating transfer value by around 25%.

In the another experiment, conducted as a part of on number 0462. STZ.2013-2 SAN-TEZ project (Industrial Thesis Supporting Program of Ministry of Science, Industry and Technology), in the test room had five different volumes as follows: ceiling, internal volume, external volume, floor and working volume which sized 4x4x3. Walls of the test room has the same U value with the hybrid wall design. There isn't a window in the test

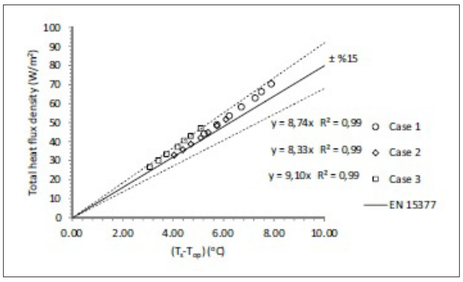


***Figure 6.*** *Heating capacity of radiant heating wall panel system (TSE 825, 2008).*

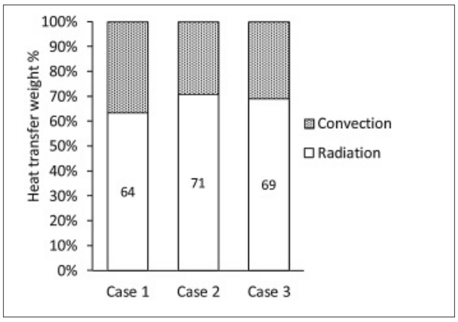


***Figure 7.*** *Radiant heat transfer weight (TSE 825, 2008).*

room. Experiments were made for 9 situations; at -3°C, 0°C, 5°C outdoor temperatures and at 32°C, 35°C and 40°C radiant panel water temperatures. Analyses started when hot water sent to the wall and room temperature, radiant temperature (RT), PMV, PPD values measured for the periods of 15 minutes, on 5 points and at three heights (0,3m, 0,6m, 1,1m) from floor in the working room.

When analyzing the results of the experiments, radiant temperatures which affects people more were higher than room temperature for each condition and each temperature. PMV measurements came to comfort range between 30 minutes to 1 hour during the measurement period. In all condition, PMV values were in the comfort range when room temperature entered

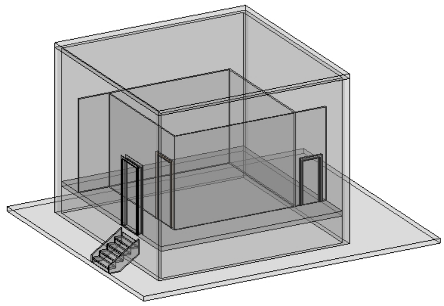

***Figure 8.*** *3D model of test room.*

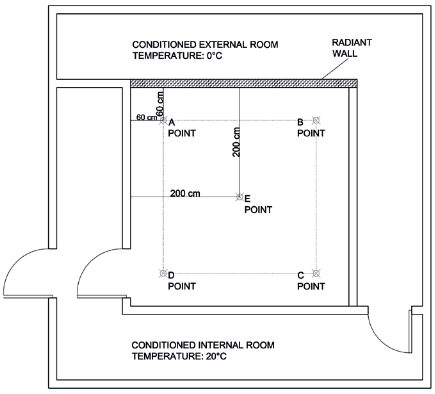


***Figure 9.*** *Plan of test room.*

regime. The biggest advantage of the heating system although heating from single surface, PMV values were very close on all points and heights when room temperature entered regime. This situation shows us, the radiant wall system reduces temperature differences between ceiling and floor and eliminate "radiant temperature asymmetry" compared with conventional heating systems so the comfort temperature would be achieved in a shorter time by spending less energy.

Within the scope of SAN-TEZ project has been continued based on the data provided by the predesign study, modular hybrid wall elements are systematically created by explaining the

***Table 1.*** *Comparison of Conventional Building Envelope and ready wall with heating and cooling system [5].*

| | | **Conventional building envelope cross-section** | **Ready-wall with heating and cooling system** |
|---|---|---|---|
| **Dimensions** | **h:height** | Variable | 2.80m, 3.00m |
| | **d:width** | | 0.60m, 1.20m |
| **Design and implementation** | | Common | Less common |
| **Construction speed** | | Slow | Fast |
| **Standardization** | | Yes | No (not yet) |
| **Quality control** | | Yes | Unspecified |
| **Cost analysis** | | Yes | Variable |
| **Changeability** | | Yes | Unspecified |

election and implementation reasons for sizing, wall product classification, cross-section formation and assembly - implementation details and tested for performance evaluation.

### 3.1. Comparison of conventional wall and modular wall element

Information such as the dimension restrictions of the zoning regulation, structural function, the carrier system and axis ranges was compiled from the preliminary studies. The modular wall element based on such information, the building function (residence) where will be used the most was compared in terms of different parameters in Table 1 below by taking into consideration the construction system (the carrier system and axis ranges).

The ready wall product defined as a ready wall with heating and cooling system and the conventional system are compared in terms of thermal comfort in Table 2 below.

## 4. Results

This study with a limited scope evaluates the modular hybrid wall elements with modular surface heating and cooling system whose experimental analyses are ongoing. The predesign studies of San-Tez project coded under 0462. STZ.2013-2 and the test results of the project coded under TEYDEP 3100577

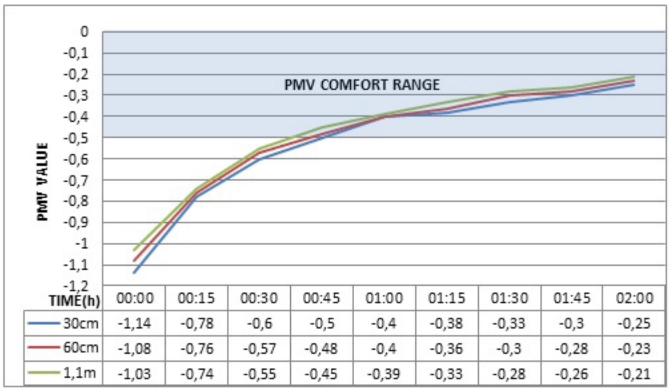


*Figure 10.* *PMV values of A point at 0,3-0,6-1,1m. heights in the condition of outside temperature at 0°C, radiant wall water heat at 35°C.*

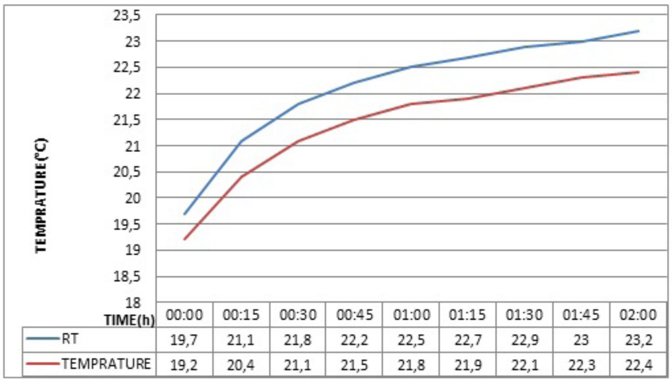


*Figure 11.* *A point air temperature and radiant temperature values at 60cm. in the condition of outside temperature at 0°C, radiant wall water heat at 35°C.*

are compiled for thermal comfort, energy efficiency and energy saving of the ready wall product.

*Table 2.* *Thermal Comfort Comparison of the ready wall and conventional system.*

| Ready wall with heating and cooling system | The wall and heating and cooling system applied separately |
|---|---|
| In systems where heating and cooling from the wall the ambient air temperature pattern is homogenous. Therefore, the heat exchange between the human body and the environment is also homogenous. | The regional temperature differences are high in conventional heating and cooling and therefore, the heat exchange between the human body and the environment is not homogenous. |
| The wall with heating and cooling system is compliant with renewable energy systems and alternative energy resources since it can reach the comfort temperature with water with low temperature (35-45°C) in the wall. Therefore, this system can work both with the conventional (gas, oil, power) and alternative energy resources. | Since the conventional heating system requires reaching high temperatures, the renewable energy systems and alternative energy resources are mostly not efficient. They can work more efficiently with conventional (gas, oil, power) fuels. |
| The pipes in the walls with heating and cooling system distribute the heat equally to every corner of the venue. Heat transfer mostly occurs through panels. Since the wall being the largest surface area surrounding a space transfers heat via panels, it provides comfort at lower ambient temperatures compared to the conventional system. | Radiation and convection heat transfer occur in conventional heating system via regional heating elements with high temperatures. Fans are needed for air movement in the internal space in some systems. The point where the heaters are located within the room is heated more and hot air rises to the top of the room fast. The temperature difference between the ceiling and floor will be great. More energy and time is spent to reach the comfort temperature. |

This new product created to improve the energy use and comfort conditions provides advantages in terms of construction, transportation and assembly stages compared to the conventional wall systems. The wall elements with surface heating system is known to provide total heating energy saving of around 20% compared to the floor heating system (Koca et al., 2014). The study aims to increase the comfort condition regarding usage and efficiency by reducing the cost of energy. Carrying out more researches with experimental studies to ensure that the ready wall product created is a good alternative to the conventional systems will increase the effect level of the thermal comfort parameters.

**Acknowledgements**

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