DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

HEATING CONTROL IN SMART CLOTHES

by
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İZMİR

HEATING CONTROL IN SMART CLOTHES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“HEATING CONTROL IN SMART CLOTHES”** completed by **GÜRCAN KAHRAMAN** under supervision of **Yrd. Doç. Dr. ÖZGE ŞAHİN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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HEATING CONTROL IN SMART CLOTHES

ABSTRACT

With the new technologies, intelligent systems have been worked for many studies in recent years. These systems have been developed for different type of application area with the different functional ability. One of this area is textile industry. Intelligent systems have been applied with a wide frame in textile industry and improve day by day so fastly. New systems have been improved for textile industry as electronic substructures combine with textile material instead of basic textile materials, which reaction variously physical and chemical according to media temperature.

One of these types of application is intelligent clothes, which use heat function according to media conditions. In the future, this kind of clothes will be more applicable in daily life. These clothes will be designed for especially people, who work outside. It is important that clothes need to supply their own basic clothes function but at the same time they need to supply their heater function with carrying of electronic body on the structure. Because of mobility of clothes body, studies are important about focusing on resisting and using time parameters of any intelligent clothes.

In this project, electronic sub structure for heat functional clothes had been developed with carry on electronic property. Heater panels had been produced on the clothes by steal based conductor threads to supply heating function. Fit with the these panels, optimum power source, electronic user interface card, control card which activate or deactivate the heater panels and control the system and a waistcoat to carry all these materials, had been designed and produced. System had been tested on a thermal model and simulated cold media conditions.

Keywords: Intelligent clothes, electro-textiles, textile basis conductor bodies, steal threads, heating, and heater clothes.

AKILLI GİYSİLERDE ISITMA KONTROLÜ

ÖZ

Akıllı sistemler son yıllarda çeşitli çalışmalara konu olmuş, bu sistemler farklı alanlarda değişik işlevler yerine getirecek şekilde geliştirilmiştir. Bu alanlardan biri de tekstildir. Akıllı sistemler tekstil sektöründe de günden güne artan uygulama alanı bulmaktadır. Ortam sıcaklığına göre fiziksel veya kimyasal olarak tepki veren tekstil malzemeleri yanısıra elektronik yapıların tekstil materyallerinin bir parçası olacak şekilde yapılarda geliştirilmiştir. Bu tip uygulamalardan biri de ortam şartlarına uygun olarak ısıtma fonksiyonun yerine getiren akıllı giysilerdir. Bu tip giysiler gelecekte günlük hayatımızın bir parçası olacaktır. Özellikle dış ortamlarda çalışan kişiler için tasarlanan bu tip akıllı giysiler, temel giysi özelliklerini sağlaması, bir yandan da ısıtma fonksiyonunu yerine getirebilecek elektronik yapıyı üzerinde taşıyabilmesi gerekmektedir. Taşınabilir bir yapı olduğu için dayanıklılık ve kullanım süresi çalışmanın önemli parametreleridir.

Bu çalışmada elektronik özelliklere sahip bir ısıtma fonksiyonlu giysinin elektronik altyapısı geliştirilmiştir. Isıtmanın sağlanması amacıyla çelik malzemeden yapılmış iletken iplikler kullanılarak ısıtıcı paneller üretilmiştir. Bu ısıtıcı panellere uygun olarak optimum bir güç kaynağı, kullanıcının sisteme müdahale edebilmesini sağlayan bir elektronik arabirim kartı, sıcaklıkların devamlı olarak okunup ısıtıcı panelleri otomatik olarak devreye alıp çıkaran ve sistemi kontrol eden bir elektronik kontrol kartı ve bütün bu materyalleri üzerinde taşıyabilecek yelek tasarlanmış ve üretilmiştir. Sistem termal model üzerinde test edilerek soğuk ortam şartları simüle edilmiştir.

Anahtar Kelimeler: Akıllı giysiler, elektro-tekstiller, tekstil esaslı iletken yapılar, çelik iplikler, ısıtma, ısıtıcılı giysiler

CONTENTS

CHAPTER ONE
INTRODUCTION

This chapter introduces the research presented by the thesis. The first section of this chapter briefly explains what smart clothes are and general information about smart textile. Second section gives outline of the thesis.

1.1 Smart Clothes

Nowadays, the textile industry is interested in new topics: “intelligent textiles”, “smart clothes”, “i-wear” and “fashion engineering” are only a few of the keywords. Modern communication or monitoring systems or the development of new materials with new functions has just started with timidity, but the branch already makes an enormous boom for this sector. Very smart textiles can sense react and adapt themselves to environmental conditions. They are the highest level of smart textiles.

People have always been inspired from the nature in order to create our clothing materials with higher levels of functionality and intelligence. The development of microfiber is a very good example, starting from studying and mimicking silk, then creating finer and, in many ways, better fibers. However, up to now, most textiles and clothing have been lifeless. It would be wonderful to have clothing like our skin, which is a layer of smart material. The skin has sensors which can detect pressure, pain, temperature, etc. Together with our brain, it can function intelligently with environmental conditions. It produces large quantities of sweat to cool our body when the surroundings are hot, and makes the blood circulation fast when cold. It changes its color when exposed to a higher level of sunlight, to protect our bodies. The skin can shed, repair and regenerate itself. To study and then develop a smart material like our skin is itself a very challenging task.

In the last decade, research and development in smart/intelligent materials and structures have led to the birth of a wide range of smart products in transportation, telecommunications, homes, buildings and some areas have reached the stage where industrial application is both feasible and viable for textiles and clothing.

Many applications have been demonstrated worldwide. Extended from the space program, heat generating, storing fibres, fabrics have now been used in skiwear, shoes, sports helmets and insulation devices. Textile fabrics and composites integrated with optical fibre sensors. The first generation of wearable motherboards has been developed, which have sensors integrated inside garments and can detect information regarding injury to and health of the wearer, and transmitting such information remotely to a hospital. Fibre sensors, which are capable of measuring temperature, strain/stress, sensing gas, biological data and smell, are typical smart fibres that can be directly applied to textiles. Clothing with its own senses and brain, such as shoes and snow coats which are integrated with Global Positioning System (GPS) and mobile phone technology, can tell the location of the wearer and give him/her directions. Incorporating of electronic devices into textiles leads to new branch of science called textronics.

Textronics mean that we can create products which enable effective supervision and protection of human health (Xing, Z.,2001). The inbuilt electronic systems support the products' interactivity by introducing sensors and electronic & piezoelectronic elements into the textile layers of the product. Most vital is the application of textronic products in rehabilitation and medical diagnostics. An example of a system for tele-rehabilitation is presented in Figure 2. The use of double-acting, touch-sensitive, interactive clothing elements and interfaces enables the medical specialist to supervise a patient's action.

Thanks to textronics, we can design shirts replacing electrocardiography devices; for example, the new 'Life Shirt' technology connects a T-shirt to a set of sensors monitoring 30 physiological signals.

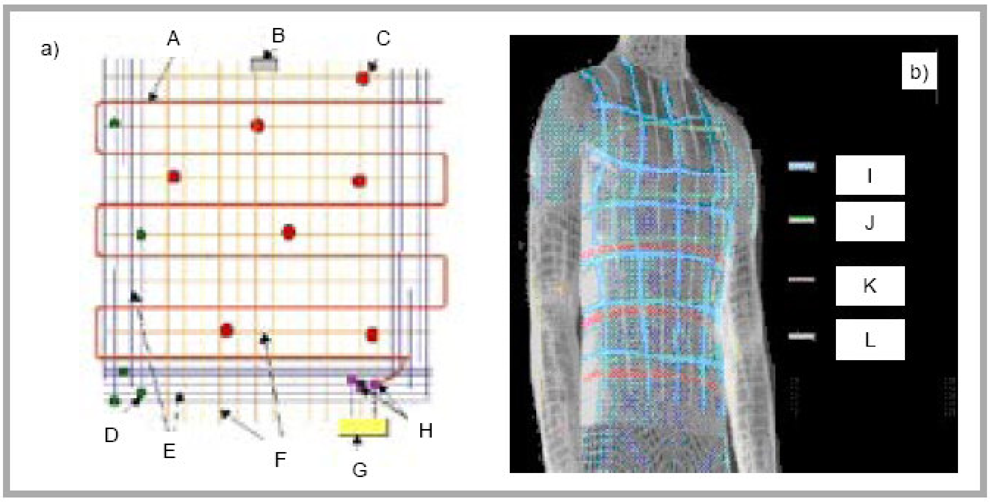


Figure 2.1 The idea of textronics

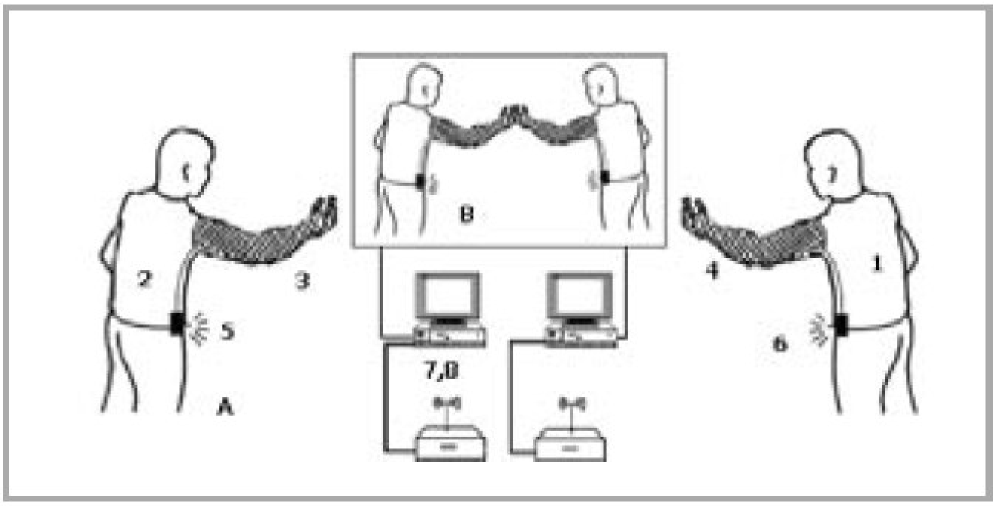


Figure 2.2 System of tele-rehabilitation

Including the electrical wiring into the structure of the textile material is the basic step in developing textronics Incorporated electrical connections which cannot be distinguished from the clothing used at present would be the best result. It will be possible to realize such a vision when user-friendly electronic woven & knitted fabrics and nonwovens are developed and the functional elements would be integral components of the product. Therefore the basic aim was to approach the development of new textile technologies which would include electronic circuits, electro-conductive-, piezo- and opto-electronic elements and other sensors into the textile structures.

A new property of clothing would be the possible to exchange information. If clothing would be capable of recording, analyzing, storing, sending and displaying data, a new dimension of intelligent high-tech clothing could be reached (Kirstein, T.,2002). Especially applications for the health and military sector are already guessed a great demand (Xing, Z.,2001). Considering the needs of 'the warriors of the future', some military materials become a part of the uniforms. Global positioning systems, chemical detectors, personal physiological status sensors, helmet systems that equipped with displays-microphones-head phones, local networks, protective uniforms for environmental conditions, special fabrics for providing the best camouflage are some of the examples of such systems.

Developments in telecommunication, information technology and computers are the main technical tools for Telemedicine (Telecare, Telehealth, e-health) now being introduced in health care. Telemedicine - medicine at a distance - provides the many possibilities for doctors to more easily consult each other. For individuals, e.g. with chronic diseases, "Telemedicine" means, the possibility to stay in contact with their health care provider for medical advice. This provides new possibilities for personalized health and health care. The results of the researches will make a positive impact on the quality of life for individuals in the real life.

1.2 Outline of the Thesis

The first chapter is an introduction chapter. General information about thesis, outline of the thesis is explained at this chapter. The second chapter explains the basic background needed during the thesis design and realization. General information about smart textiles and smart textile applications are explained at second chapter. At Chapter 3, the hardware requirements are determined and based on this information hardware design is explained. Chapter 4 concerned with measurements.

CHAPTER 2
RESEARCHES ON SMART CLOTHES

2.1 Intelligent Textiles

The development of wireless computing and miniaturization of electrical components have accelerated the production of different wearable devices such as pocket computers and mobile phones. This equipment is worn or carried almost constantly. Instead of having separate devices located in pockets, wearable systems can be integrated into clothes where they can form a network of intelligent devices. Clothes themselves are naturally near to a user. Therefore, clothing provides an ideal platform to embed sensors inside garments and to perform measurements that apply personal psychological signals. In addition user measurements, it is often beneficial to perform measurements from the surrounding environment. Results from these measurements can be used for controlling the devices that are integrated into the clothing. These kind of systems are called smart clothes. Their purpose is to enhance or augment the functions of ordinary clothes via added electrical and non-electrical intelligent components.

Smart textiles have been paid attention in recent years and there will be increase in research of their development and applications in the next few years. Some research areas and applicaions are mentioned below about smart textiles.

2.2 Military Aspects of Smart Textiles

During the last decade, there is an increasing interest in integrating electronic capabilities and components with textile materials and soldier equipment.

Future soldier systems already being planned have heads-up display, wireless weapons, global positioning systems, chemical and biological threat detectors, battery power, personal physiological status sensors, combat ID sensors as shown in Figure 1. All linked up to the soldier’s personal computer to assist in situational awareness and understanding. Network cables for data and power transmission and a variety of antennas for near and remote communication need to be integrated in to the warrior's clothing and equipment to reduce weight and bulk of current electronic system interface. Active intelligent textile systems have the capacity of improving the soldier's performance by sensing and responding to a situational combat.

Figure 2.3 Soldiers of the Future

Nanotechnology will play a major role in the development of the new generation of army uniforms and equipment. By changing the properties of materials, such as by introducing tiny nanoparticle reinforcements into polymers, nanotechnology will enable such advances as making helmets 40-60% lighter and creating tent-fabric that repairs itself when it rips. With the advent of nanotechnology, chemical protective over garments, which shield soldiers against hazardous chemicals and deadly micro-organisms, will enter a new phase of development. The new uniforms will be breathable and 20% lighter in weight than the standard battle-dress over garment. With nanotechnology, some properties can be added to materials that weren't there before (Veltman, C.,2002).

There are some institutes and research centers that works on military products of the future. Much of the smart-fabric, "soldier of the future" research is centered at the US Army Soldier Systems Center. There, scientists and technologists, are studying on variety of textiles that can transport power and information. One example is a soldier sticking his intelligent glove finger into water to see if it is safe to drink.

Among the goals of the newly-created Institute for Soldier Nanotechnology (ISN) will be gadgets that can heal soldiers, uniforms that are nearly invisible and clothing that can become a rigid cast when a soldier breaks his or her leg (Wakefield, J.,2002).

The Defense Advanced Research Projects Agency (DARPA) focuses on researches in the area of 'Electronic Textiles' besides other next generation products. The DARPA mission is to develop imaginative, innovative and often high-risk research ideas and to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

Army Research Laboratory and Army Soldier Systems works with Massachusetts Institute of Technology (MIT) to equip future soldiers with uniforms and gear that can heal them, shield and protect them against Nuclear-Biological-Chemical (NBC) warfare.

The areas of interest that are being explored under the research and developing programs in these institutes, centers and universities about this topic include:

Integration of low level conductive channels in textile materials to allow plug-in sites to join power source with equipment points;

Antennas are built into textiles materials and they are visually covert and body conformal;

Multiple path conductive and optical networks for data and power transmission enabling physiological and environmental sensors;

Textile based computer peripheral devices (keyboards, touch-pads and displays);

Integration of solar generating components into textiles;

Integration of conductive plastic battery (rechargeable) material into textiles.

2.2.1 Helmets

In the past, soldiers had to use printed maps. But with the Land Warrior suit, each soldier can get the information in very short time via a helmet-mounted Global Positioning System (GPS), a small wireless voice and data communication system, and a wearable computer linked to wireless LAN (Local Area Network).

A display on the helmet allows the soldier to scan the surroundings in the darkness, using thermal and night-vision sensors connected to his weapon. This display also gives each soldier a view of a situation map that can pinpoint where both friends and foe are located, in real time. If he's on a battlefield, he can call in fire, just like sending in an e-mail. He'll specify the kind of attack. It's sent, it happens, and just that easily, he's in touch with his commanders. On the other hand, an electric wire integrated into a helmet cover would be connected to another part of the uniform. The goal is to provide the war fighter with executable functions (Akhtar, H.,2002).

Figure 2 shows a helmet. It illustrates how an electrical wire can be embedded in fabric through stitchless seam technology.

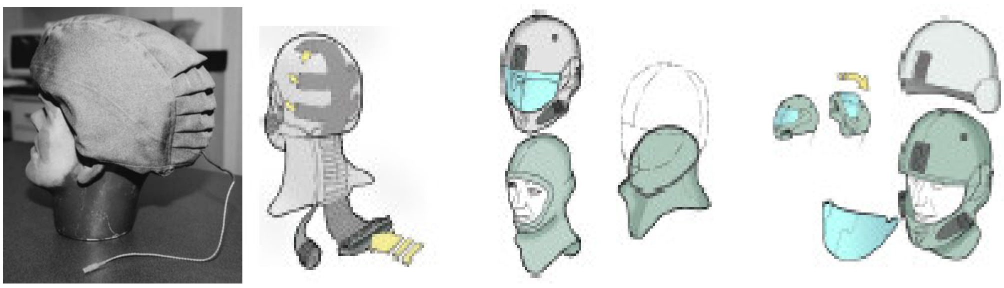


Figure 2.4 Next generation helmets

Modular/Integrated Communications Helmet (MICH) provides the soldier the flexibility to tailor ballistic/impact protection and communications to the mission using one modular system. MICH is a modular helmet system that provides ballistic, fragmentation, aural and impact protection, while being night vision, communications and Nuclear, Biological and Chemical (NBC) equipment compatible. The helmet allows maximum sensory awareness for the user, which includes unobstructed field of view and ambient hearing capabilities. It also allows mounting of night vision devices and oxygen masks. The communication subsystem is intended to provide aural protection as well as a dual channel communications capability. The subsystem provides aural protection, ear-specific communications (dual channel), low profile microphone(s), microphone adapter for mask microphone, multiple radio adapters, and push-to-talk access. As shown in Figure 2.5, the headset may be worn alone or with the ballistic helmet retention system and pad suspension system.

The Advanced Combat Vehicle Crewman's Helmet (ACVCH) Ballistic Shell has protection level equal to the current infantry helmet and has the configuration of the standard CVC shell. The helmet design incorporates an electronic "Talk Through" communications capability with passive hearing protection incorporated into the standard communications headset for vehicle intercom and squad radios. In Figure 2.6, Advanced Combat Vehicle Crewman's Helmet (ACVCH) is illustrated.

Figure 2.5 Modular/Integrated Vehicle Communication Helmet

Figure 2.6 Advanced Combat Helmet

2.2.2 Textile Based Health Products in Military

The Army isn't the only branch of the military actively developing smart textiles. The US Navy funded a project in 1996 that eventually turned into the Smart Shirt, a product commercialized by SensaTex Inc. in Atlanta, with technology from Georgia Tech Research Corp. The T-shirt functions like a computer, with optical and conductive fibers integrated into the garment. It can monitor the vital signals, such as heart rate and breathing of wearers, including security officers, military personnel, astronauts.

Sensatex is e-textile startup that is creating shirts that can be used to monitor soldier location and status in the battlefield. One of the biggest problems for medics is locating a soldier's wound and determining his vital signs in battlefield chaos. A uniform that monitors a soldier's vital signs can wirelessly relay the exact location of the wound, saving a lot of valuable time and lives. The life shirt system is a comfortable garment that can be worn under normal uniform and it can automatically and continuously monitor over 40 physical signs such as respiratory rate, ventilation, swallow counts, arterial pulse wave, hearth rate. The life shirt system is shown in Figure 5. (Satava, R.M., 2001).

Figure 2.7 Smart Shirt

On the other hand, the scientists also have a strong emphasis on nanotechnology solutions for defense against biological and chemical warfare and terrorism. Since the attacks of September 11, this effort has received greater attention with a new research and development focus on using nanotechnology for chemical/biological/radioactive/explosive detection and protection. DARPA sponsors a project about a biosensor to identify bacteriological infections in biowarfare. The American Military Institutes try to integrate wearable biosensors in clothing. The sensor can identify bacteria and they hope to have proof of principle in three years (Malsch, Ineke, 2002).

2.2.3 Interactive Camouflage

Scientists are studying on animals to develop technology that could be used for *chameleon-like battle wear* that changes color depending on its surroundings. The researches are trying to catch the interest of the military with fabrics that change color when conductive fibers stitched into the cloth heat and cool the material's thermo chromatic inks. If a soldier is leaning against a marble wall, the suit changes coloration to that, or if a soldier is lying on a black tarmac, it changes to that as shown in Figure 2.8.

It may be developed within a decade. It is an "all-seasons" waterproof suit that adjusts to the soldier's internal body temperature, eliminating the need to change clothing. He can actually go from Arctic cold to desert heat and back again. The desire of the army is achieve a fully addressable, interactive camouflage, accomplishing that would be like a space program for e-textiles (Akhtar, H, 2002).

Invisible rain coat, which is shown in Figure 2.9, is a recently developed samples of another optical camouflage technology. This product offers a fascinating sense as if the wearer is transparent. Even if it can not provide a fully invisible dressing, this extraordinary cloth makes it possible to see the objects and persons behind it. Optical camouflage technology works with a lens that placed on the back of the cloth. This lens perceives the back vision and reflects the image to the front side to provide a transparency.

Figure 2.8 Chameleon Like Battle Wear

Figure 2.9 Invisible Rain Coat

2.3 Medical Aspects of Smart Textiles

"Smart Clothing" is made from fabrics and they are wireless and washable that integrate computing fibers and materials into the integrity of the fabrics. This technology shows a quantum leap in healthcare monitoring, producing accurate, real-time result. A garment can have some functions like a computer by using optical and conductive fibers, which is shown on Figure 2.10, integrated into the garment.

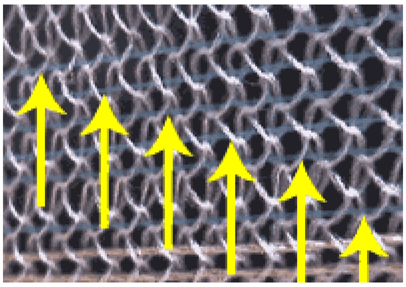


Figure 2.10 Textile Embedded Optical Fibers

When included into the design of clothing, the technology could monitor the wearer's heart rate, EKG, respiration, temperature and a host of vital functions, alerting the wearer or physical situation if there is a problem. There is a critical need for the medical smart clothing and this need will be met in the near future.

2.3.1 Smart Shirt

Georgia Tech is a university, which conducts research in the area of "intelligent fabric". Georgia Tech developed a "Wearable Motherboard" (GTWM), which was initially intended for use in combat conditions. GTWM is shown on Figure 2.11.

Figure 2.11 Georgia Tech Wearable Motherboard

The project was initially funded by the U.S. Navy in October 1996 and was developed by Georgia Tech Research Corp. of Atlanta. GTWM is currently being manufactured for commercial use (Biberdorf, C.,2002).

The commercial applications for the "Smart Shirt" are as follows:

Medical Monitoring
Disease Monitoring
Clinical Trials Monitoring
Obstetrics Monitoring
Infant Monitoring
Biofeedback
Athletics
Military Uses

The SmartShirt System includes advances in textile engineering, wearable computing and wireless data transfer to permit the convenient collection, transmission, and analysis of personal health and lifestyle data.

The SmartShirt allows the comfortable measuring and/or monitoring of individual biometric data, such as heart rate, respiration rate, EKG, body temperature, caloric burn and provides readouts via a wristwatch, PDA or voice. Biometric information is wirelessly transmitted to a personal computer.

Smart Shirt, which is wired with optical and conductive fibers, is a garment that functions like a computer. It uses embedded electro-optical fibers in the fabric for collecting biomedical information. There are no discontinuities in the smart shirt. The smart shirt is one piece of fabric without seams. Because the sensors are movable from the smart shirt, they can be placed at any location and is adjustable for different bodies. Furthermore, the types of sensors used can be varied depending on the wearer's needs. For example, a firefighter could have a sensor that monitors oxygen or hazardous gas levels. Other sensors monitor respiration rate and body temperature or can collect voice data through a microphone (Xing, Z.,2001). The information is sent to a transmitter at the base of the shirt where it is stored on a memory chip or sent to your doctor, coach or personal server via a wireless network like bluetooth, RF(Radio Frequency), WLAN (Wireless Local Area Network).

It uses plastic optical fiber and various sensors and interconnects for monitoring human body to detect any dangerous signals or other vital symptoms. A flexible data bus brings the data from sensors to emitters and then sends to PAN (Personal Status Monitor). Detailed architecture of the Smart Shirt is shown on Figure 2.11 and Figure 2.12.

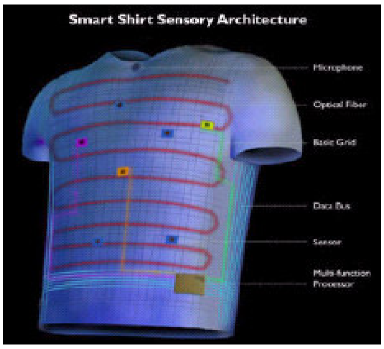


Figure 2.11 Smart Shirt

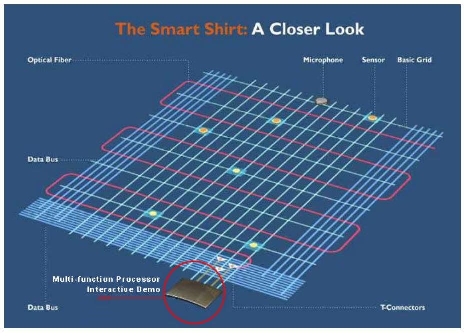


Figure 2.12 Detail of the Smart Shirt

Similarly the sensor technologies in the garment can be adapted for to meet the specific needs of the athletes, astronauts, police officers and firefighters and those involved in hazardous activities (Biberdorf, Curt, 2002).

The "Smart Shirt" system uses Bluetooth and WLAN. Both of these technologies are in their formative stages and it will take some time before they become dependable and widespread. Additionally, the technology seems to hold the greatest promise for medical monitoring. However, the "Smart Shirt" at this stage of development only detects and alerts medical professionals of irregularities in patients' vital or emergency situations. It does not respond to dangerous health conditions. Future research in this area of responsiveness is ongoing. Application areas of “Smart Shirt” are as follows:

Maintaining a Healthy Lifestyle
Individual Athletes/Team Sports
Continuous Home Monitoring
Remote Patient Examination
Infant Vital Signs Monitoring
Sleep Studies Monitoring

2.3.2 Life Shirt

Developed by Southern California-based health information and monitoring company VivoMetrics, the Life-Shirt, which is shown on Figure 2.13, uses embedded sensors and a PDA to monitor and record more than 30 physiological signs and bring standard monitoring technology out of the hospital and into the real-world environment. The information is uploaded to a computer via a data card and sent over the Internet to VivoMetrics, where it is analyzed and then sent to the physician (Wakefield, J.,2002).

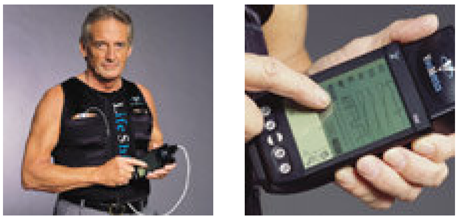


Figure 2.13 Life Shirt

The Life-Shirt System with 12 patents covering wearable sensor design and software algorithms.

2.4 Other Interesting "Smart Clothing"

There are also other "Smart Clothes" that are aimed at consumer use. For example, Philips, a British consumer electronics manufacturer, has developed new fabrics, which are blended with conductive materials that are powered by removable 9V batteries. These fabrics have been tested in wet conditions and have proven resilient and safe for wearers. One prototype that Philips has developed is a child's "bugsuit" that integrates a GPS system and a digit camera woven into the fabric with an electronic game panel on the sleeve. This allows parents to monitor the child's location and actions.

Another Philips product is a live-saving ski jacket that has a built in thermometer, GPS, and proximity sensor. The thermometer monitors the skier's body temperature and heats the fabric if it detects a drastic fall in the body temperature. The GPS locates the skier, and the proximity sensor tells the skier if other skiers are nearby. It is suggested that wearable computers will be widely used by the end of the next decade.

CHAPTER THREE
DESIGNING THE HEATING CLOTH

3.1 Heater Panels

The base function of the prepared system is to heat the user with the optimum electrical system location in the most suitable clothes construction. The basic components of the heating function are heater panels. For that reason, design and production of the heater panels, which are designed at Dokuz Eylul University Textile Engineering Department have an important case for this investigation. To avoid high amount of energy consumption, heating all the surface of the clothes hadn't been preferred. Instead of this, various parts of the clothes are heated with the help of the heater panels in this investigation.

The results of the scientific researches had been showed that conductor threads were started to use with the developed technology instead of the traditional conductor wires in the designing of heater clothes.

Various types of conductor threads had been provided in the different metallic property from local and foreign companies. At the end of the evaluations, Bekinox® conductor threads, which are 100% steal fibre, had been chosen for the production of heater panels. For that propose, It had been communicated with the "Bekaert Fibre Technologies Company", where is located in Belgium. The provision of the threads were realized for the first time in the Turkey and used first time for any Scientific Research. Some physical properties of the Bekinox® conductor threads are given in the Table 3.1.

Table 3.1 Some physical properties of the Bekinox® conductor threads

Type	Thread Thickness (tex)	Mean Break Load (N)	% Strength	Mean Linear Resistance (Ω/m)	Linear Resistance Variation
VN12/1x275/100Z/316L/HT	250	37	1	30	± % 7
VN12/2x275/175S/316L/HT	500	67	1	14	± % 7
VN12/3x275/175S/316L/HT	750	114	1	9	± % 11
VN12/4x275/100S/316L/HT	1000	163	1	7	± % 14
VN12/6x275/100S/316L/HT	1500	146	1	4,6	± % 9
VN12/8x275/100S/316L/HT	2000	187	1	3,5	± % 9
VN14/1x90/100Z/316L/HT	110	23	1	71	± % 14
VN14/2x90/175S/316L/HT	220	35	1	As to request	As to request

The coding of the thread types can be explained as;

VN --- / - x --- / ---- / --- / HT

a b c d e f g

a: Fibre diameter 12 µm (for 275 filament)

14 µm (for 90 filament)

b: Coefficient: As a standard : 1 / 2 / 3 / 4 / 6 / 8

c: Filament number: Standard : 90 / 275

d: Bending in a meter : 100 / 175

e: Bending direction : one layer Z, multi layer S

f: Steel material production standard : AISI 316 L

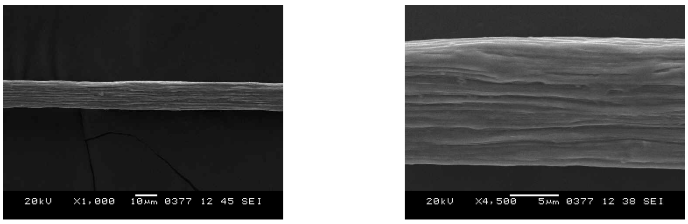
g: Heatable Textiles

Sample thread bobbins can be seen in Figure 3.5, which is proposed to be used in heater clothes prototype.

Figure 3.1 Bekinox conductor threads

The codes VN12/2x275/175S/316L/HT and VN14/1x90/100Z/316L/HT conductor threads had been used for pre-experiments. Thinness of these threads are respectively 500 tex and 110 tex. Resistances are again respectively by 14 Ω/m and 71 Ω/m. The main reason of choosing of these threads is that electrical parameters (resistance values and resistance variations) are more suitable than the others for using them for the purpose of heating. According to heating data for pre-experiment results, which were worked with both two thread samples, the thread that coded by VN12/2x275/175S/316L/HT was chosen (500 Tex thinness and 14 Ω/m resistance) for production of the heater panels.

Cross section appearance of the Bekinox® fibres were obtained by JEOL-6060 Scanning Electron Microscope-SEM. Figure 3.6 (a) and (b) shows lengthwise appearances with 1.000 and 4.500 times bigger.



(a) (b)

Figure .3.2 Bekinox conductor thread lengthwise appearance
(a) 1.000x (b) 4.500x

Pre-experiments with this conductor threads of weaving and arising of clothes had been started in the textile atelier of the Dokuz Eylül University Textile Engineering Department. Structure of the heater panels had been produced in a Company, where they have industrial type narrow clothing workbenches, with using two types of conductor threads. In these structures, conductor threads had been used in shawl direction and polyester threads had been used in warp direction.

Heater panels had been produced in industrial type clothing workbenches because industrial type clothing workbenches are produced more homogeneously and smoothly compared to hand type clothing workbenches.

Production of heater panel structure and closely appearance were given in Figure 3.7. As it can be seen in figures, conductor threads were located parallel to each others. To obtain a suitable structure for classical resistance, thread had been entered one point until finishing of lie operation. Then, thread had been exited other point without any cut off and short circuit during transportation. This type of structure is the best choice for electrical current trials.

Figure 3.3 Formation of a heater panel by knitting with warp method

To control obtained heat, which needs to be satisfying amount, pre-experiments were realized with the heater panels. Experiments had been done with different quantity of heater panels as 2-ply, 3-ply and 4-ply. Results showed that it is more accurate that using 2 or more ply panels than 1-ply. Location sample of heater panels in clothes structure is given in Figure 3.8.

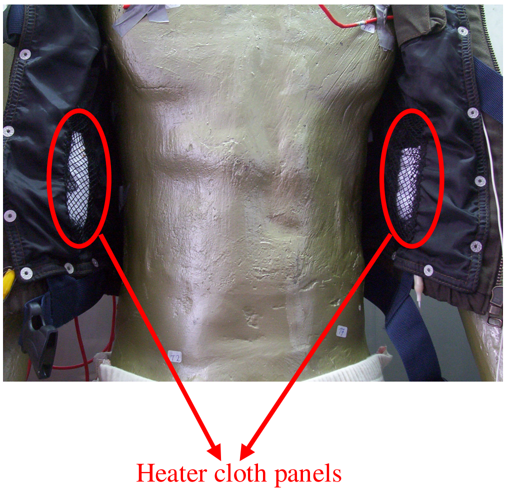


Figure 3.4 Location of the heater panels in clothes

3.3 Electronic Circuit Design for Heater Panels Prototype

In this work, a temperature control circuit, which operates or stops the heater panels, is designed with the study on temperature measurement and comparison.

Electronic sub-structure of the heater clothes can be separated into three base parts according to the using purpose. These parts include measurement system, power source and user layer. Measurement system includes four temperature sensors which transfer temperature values to the system. User surface includes a keyboard and a digital indicator panel. User layer is used to show the temperature values that obtained by temperature sensors and also indicate working interval that is entered by users. Power source is battery group that supplies needed energy for all the system components.

Circuits are needed to be located on the clothes, so it was preferred that dimension of the electronic cards should be small and tight as much as possible. For that reason, weight and dimension limits are important parameters for designing the circuit. It was aimed that all the system components located on clothes should be as small as possible in terms of area. The basic working principle of the electronic sub-structure was explained as;

In the temperature control, system was designed to control temperature according principle of hysteresis rule. Main purpose of this control system is minimizing the energy consumption. The desired temperature interval is defined to microcontroller by user with the help of the keyboard. Means of the temperature values, which is measured by the electronic sensors, would be calculated. The data coming from the sensors are converted to digital values and sent to the microcontroller. When this value reaches to lower limit of the working interval, activation command is sent to the heater panels and panels heat the clothes with the help of the current coming from battery group. During the heating function, temperature values and the mean value of them are also measured by sensors. Values are shown on the digital indicator and followed by the system. When the temperature rises on the defined upper limit of the working interval, stop command goes to heater system and temperature values are still followed. When the temperature decreases until lower limit, system again starts to heating function.

In this method, heater panels are activated or stopped according to the control of the heating clothes but it can be problem for the battery group. These clothes can be used effectively by the people who work outside for a long time in the cold weather.

Heater system and measurement system work with the coordination of the microcontroller, which had been put on the circuit. A Peripheral Interface Controller (PIC) had been used as a microcontroller in the circuit. Its code was written in Pic Basic Pro language. Electrically heated control system is designed as shown in Figure 3.9. The block diagram of the heater clothes prototype is given in the Figure 3.9 and also the electronic circuit diagram is given in the Figure 3.10.

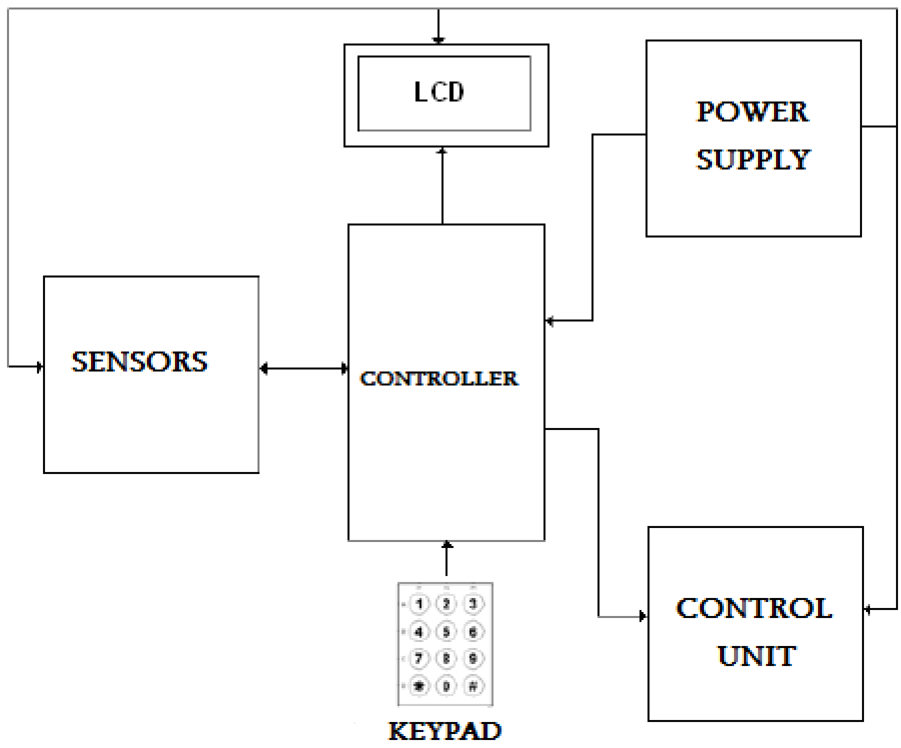


Figure 3.5 Block diagram of the heating control circuit

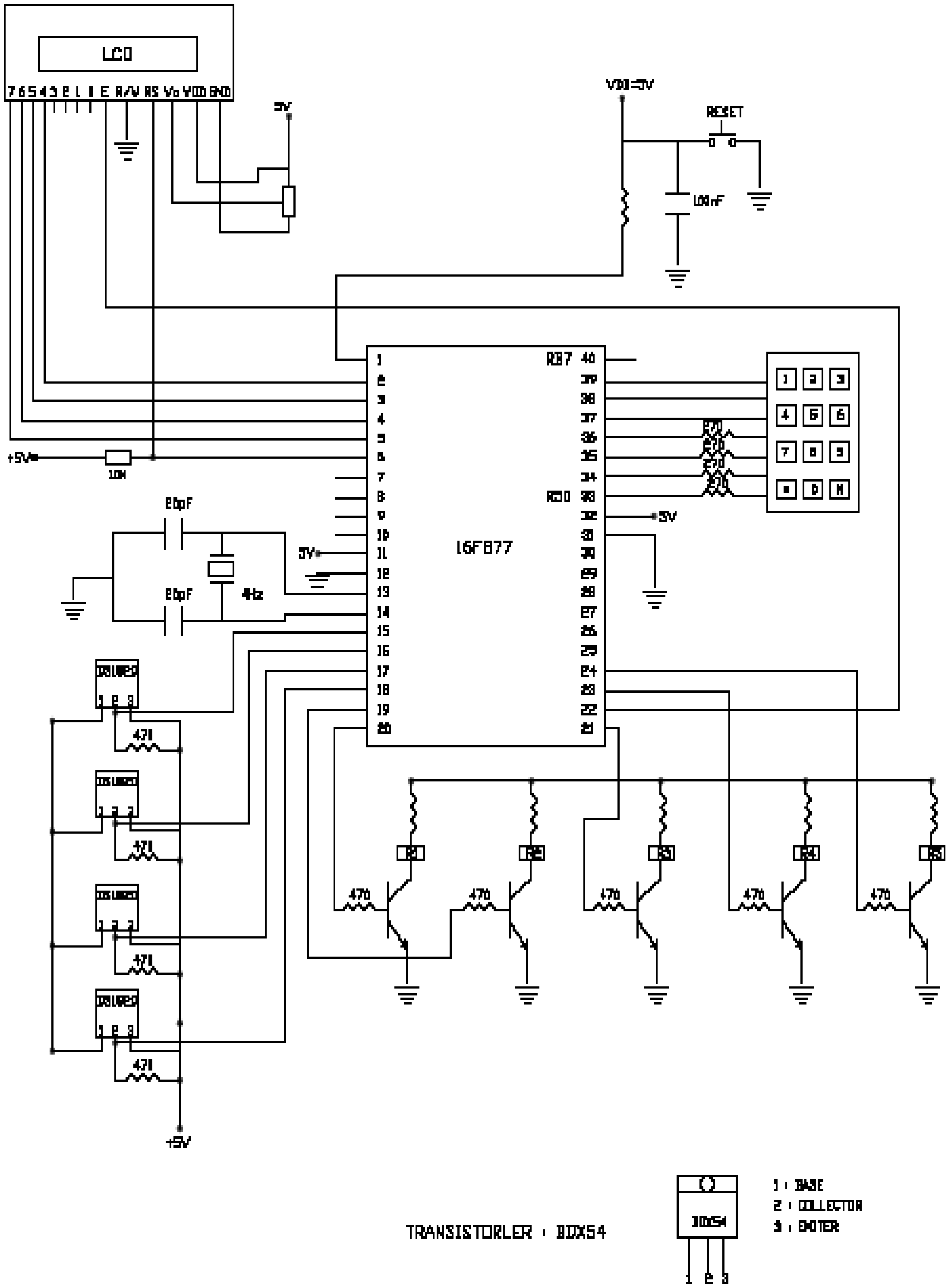


Figure 3.6 Circuit scheme for heating cloth prototype

After preparing of the electronic circuit which belongs to heater clothe prototype, pre-test were made. These test showed us that this electronic circuit was working as we wish. So the next step was minimizing the dimensions of the circuit board and some materials changed with flexible equivalents. In this way display panel and keypad separated from each other. Display, keypad and control card are connected with flexible cables. After this operation, difference between these two circuit boards is shown in Figure 3.11.

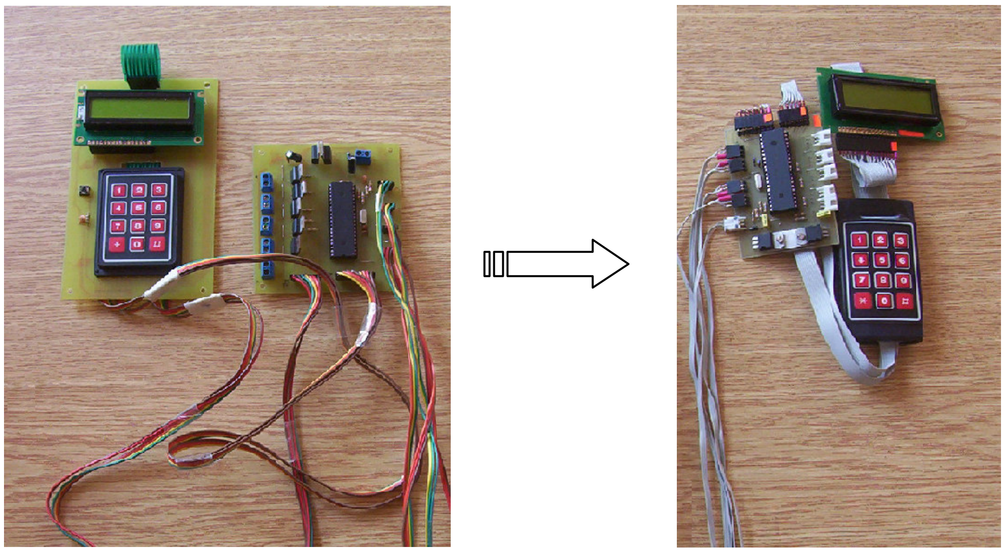


Figure 3.7 Electronic circuits

3.3.1 Microcontroller

Circumstances that we find ourselves in today in the field of microcontrollers had their beginnings in the development of technology of integrated circuits. This development has made it possible to store hundreds of thousands of transistors into one chip. That was a prerequisite for production of microprocessors, and the first computers were made by adding external peripherals such as memory, input-output lines, timers and other. Further increasing of the volume of the package resulted in creation of integrated circuits. These integrated circuits contained both processor and peripherals. That is how the first chip containing a microcomputer, or what would later be known as a microcontroller came about. As with everything that is good, this powerful component is actually very simple in its essence. It was built using the tested solutions and ingredients by the following recipe:

- Processor was removed from the simplest of computers to be used as the "brain" for the upcoming system.
- Depending on the taste of manufacturers, some memory was added, a few A/D converters, timers, I/O communication lines, etc.
- It was all placed in a standard casing.
- Simple software that everybody could learn was developed for controlling the thing.

A variety of microcontrollers has been constructed in this manner, becoming a subtle of man yet indispensable companion in everyday life. Their incredible simplicity and flexibility has earned our trust awhile ago - if you have an idea of utilizing a microcontroller for the most trivial of tasks, know that somebody has already been there.

There are three decisive facts responsible for such a success of microcontrollers:

- Their powerful, cleverly chosen electronics is able to control a variety of processes and devices (industrial automatics, voltage, temperature, engines, etc) independently or by means of I/O instruments such as switches, buttons, sensors, LCD screens, relays...
- Their low cost makes them suitable for installing in places which attracted no such interest in the past. This is the fact accountable for today's market being swamped with cheap automatons and "intelligent" toys.
- Writing and loading a program into microcontroller requires practically no previous schooling. All that is required is: any PC (software is very friendly and intuitive) and one simple device (programmer) for loading a written program into microcontroller.

3.3.1.1. PIC 16F877

PIC16F877 was used as a microcontroller in this project. Its code was written at Basic code. Pin diagram and block diagram of PIC 16F877 are shown in Figure 3.12 and 3.13. Microcontroller core features are those.

- High performance Reduce Instruction Set Computer Central Process Unit (RISC CPU)
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20MHz clock input
- DC – 200ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes electrically erasable programmable read-only memory EEPROM Data Memory
- Pin out compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Star-up Timer (OST)
- Watchdog Timer (WDT) with its own on chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed Complementary Metal Oxide Semiconductor (CMOS) FLASH/EEPROM technology
- Fully static design

- In-Circuit Serial Programming (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage rate: 2.0V to 5.5V
- High Sink/Source Current: 25mA
- Commercial, Industrial and Extended temperature ranges
- Low-power consumption:
    - < 0,6 mA typical @ 3V, 4MHz
    - 20 µA typical @ 3V, 32 KHz
    - < 1 µA standby current

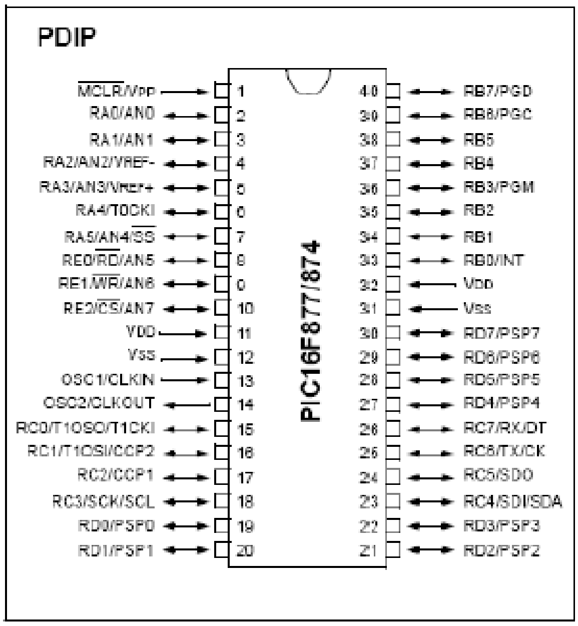


Figure 3.8 Pin diagram of the PIC 16F877

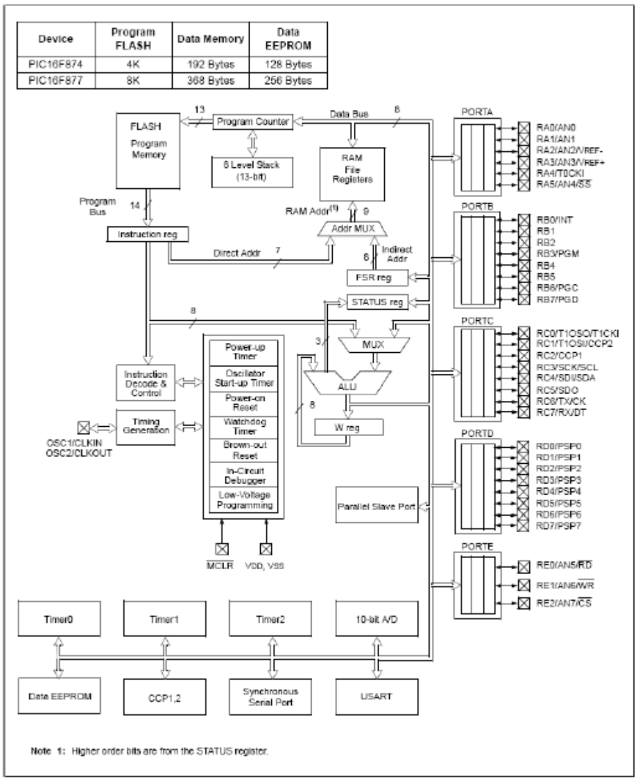


Figure 3.9 Block diagram of the PIC 16F877

3.3.1.2. Software "Pic Basic Pro"

BASIC is still considered by many PC users to be the easiest programming language to use. Nowadays, this reputation is being shifted to the world of microcontrollers. BASIC allows faster and much easier development of applications for PIC compared to the assembly language MPASM of Microchip. When writing the code for MCUs, programmers frequently deal with the same issues, such as serial communication, printing on LCD display, generating PWM signals, etc. For the purpose of facilitating programming, BASIC provides a number of built-in and library routines intended for solving these problems.

As far as the execution and program size are in question, MPASM has a small advantage in respect with BASIC. This is why there is an option of combining BASIC and assembly code assembly is commonly used for parts of program in which execution time is critical or same commands are executed great number of times. Modern microcontrollers, such as PIC, execute instructions in a single cycle. If microcontroller clock is 4MHz, then one assembly instruction requires 250ns x 4 = 1us. As each BASIC command is technically a sequence of assembly instructions, the exact time necessary for its execution can be calculated by simply summing up the execution times of constituent assembly instructions.

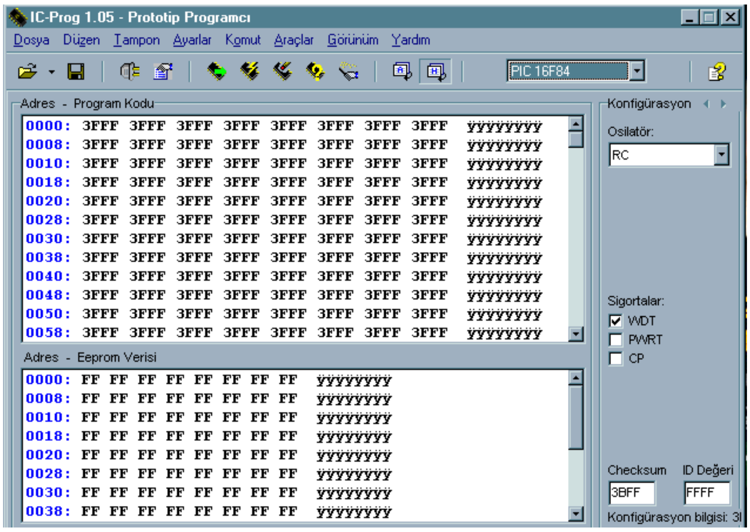


Figure 3.10 Sample viewing about pic programming software

3.3.1.3. Digital Display Panel (LCD) and Keypad

On display board, Liquid Crystal Display (LCD) HY-1602B-203 is used. Character capability of display is 16x2. It is needed 5V activate voltage. In circuit of HY-1602B-203, 0-20KΩ potentiometer is used for adjusting contrast of display. Photo of the LCD is shown in Figure 3.15 and its input -output block diagram is shown in Figure 3.16.

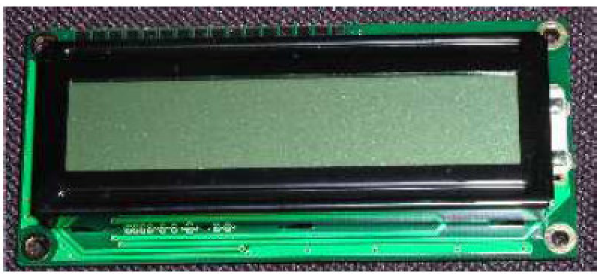


Figure 3.11 HY-1602B-203 LCD

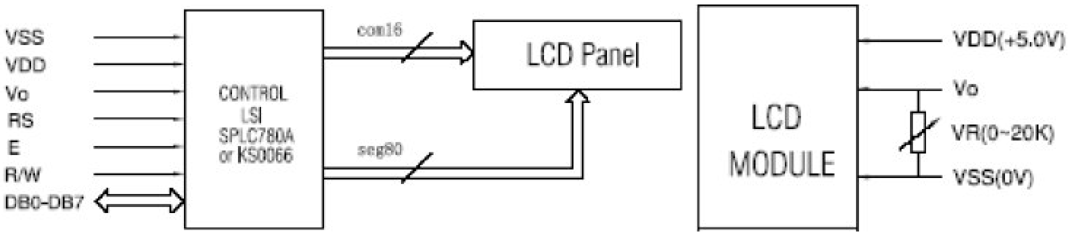


Figure 3.12 Input -output block diagram of LCD

Keypad has 4x3 dot matrix keypad. LCD panel and keypad is shown in Figure 3.17.

Figure 3.13 Digital display and keypad

3.3.1.4. Temperature Sensors

In this research, it is the main criteria to decide in which temperature interval system will be active or passive. To determine this interval, it is required to measure and observe body heat and ambient temperature. For this purpose digital temperature sensors is used.

Dallas/Maxim DS18B20 is used as temperature sensors. It has high definition on temperature measuring and have serial digital output pins. DS18B20 integrated circuit is shown in Figure 3.18.

(a) (a) (b)

Figure 3.14 DS18B20 views (a) front side (b) bottom side

DS18B20 has a one wire microprocessor interface, one wire serial digital outputs. So there is no need to use A/D converter to get and perceive temperature data. DS18B20 can be used between (-55) and +125 °C temperature interval.

Pic Basic Pro allows programmer faster and much easier development of applications for PIC. This property is also valid for serial data reading. Pic Basic Pro has a special build-in for the purpose of serial data reading for example OWOut and OWIn. One program example is given below related with serial data reading from DS18B20:

OWOut DQ1, 1, [$CC, $BE]

OWIn DQ1, 0, [temperature1.LOWBYTE, temperature1.HIGHBYTE, Skip 4, count_remain1, count_per_c1]

temperature1 = (((temperature1 >> 1) * 100) - 25) + (((count_per_c1 - count_remain1) * 100) / count_per_c1)

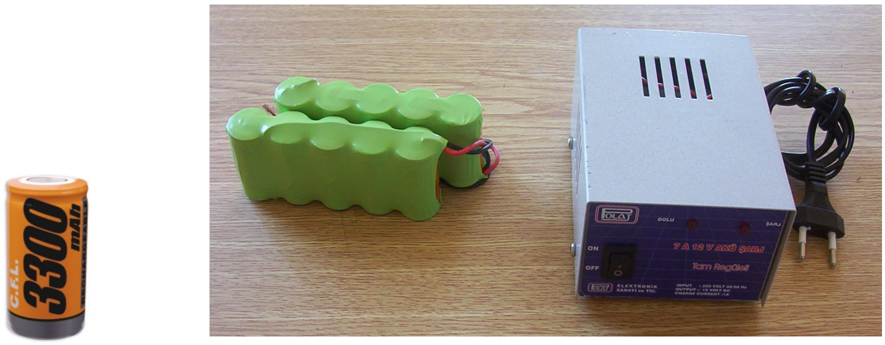
3.3.1.5. Power Supply

For selecting power supply, the first criterion is easy moving capability, which means power supply should be configured with considering the usage place. Heating function needs much more energy according to other trials. If we consider the materials that are used in this research, power supply unit is the heaviest material on the system. It is better on these applications that battery configurations constituted to get appropriate energy. So it is tried to constitute the best configuration for optimum energy and dimensions.

Minimum operating voltage of digital display and control circuit should be 5V. So 6V batteries are used. For this voltage tests, circuit scheme of the power supply is shown in Figure 3.19.

Figure 3.15 Power supply circuit

For determining the combination of the battery, some tests are made using 6V 3000 mAh and then 12V 3300 mAh Ni-MH batteries. As a result, satisfying time and temperature data couldn't be obtained using 6V batteries. Primarily it was decided to use 12V battery groups.



(a) (b)

Figure 3.16 (a)Ni-MH battery (b) Ni-Mh battery group and charge device

3.3.1.6. Transistors

In this research, heater panels should be active or passive according to the ambient temperature. For this purpose, for switching on the heater panels to heating mode, BDX53C Darlington type power transistors are used. Schematic and collector saturation region graphic of Darlington Transistors are shown in Figure 3.22.

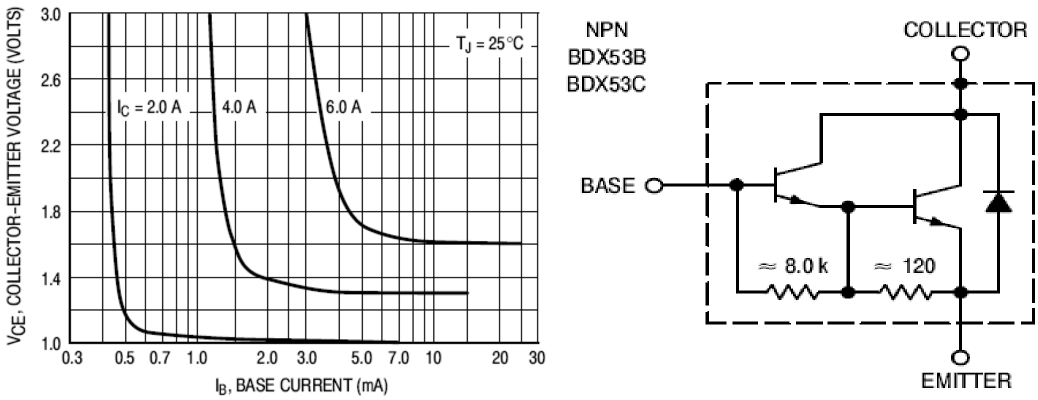


Figure 3.18 Collector-Emitter Saturation Voltage and internal shematic diagram

For switching the heater panels, transistors should work in saturation region. In the transistor circuit, base currents of transistors are 25mA and collector currents are less then 2A. So it can be concluded that transistors work in saturation state, according to the collector saturation region graphic of transistor on Figure 3.22.

3.3.3 Control System

When this research is begun, on-off control system is decided to realized using PIC16F877. In this method, one set point data is given by user using keypad. On-off control graphic is given on Figure 3.23.

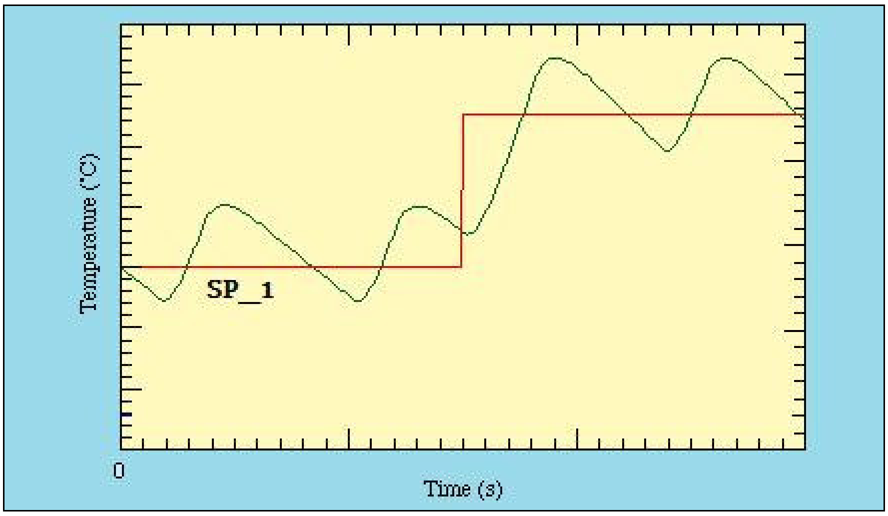


Figure 3.19 On-Off Control Graphics

In this method, when the ambient temperature of the sensor is cooler than the set-point temperature, the transistors are turned on at maximum power and once the temperature that is read from the sensor is bigger than the set-point temperature the heater is switched off completely. As a result of this method, system batteries are activated and deactivated frequently to prevent temperature and this makes the batteries lives shorter.

After that, for the purpose of having longer battery life, hysteresis characteristic is added the system. Hysteresis characteristic added on-off control graphic is given on Figure 3.24.

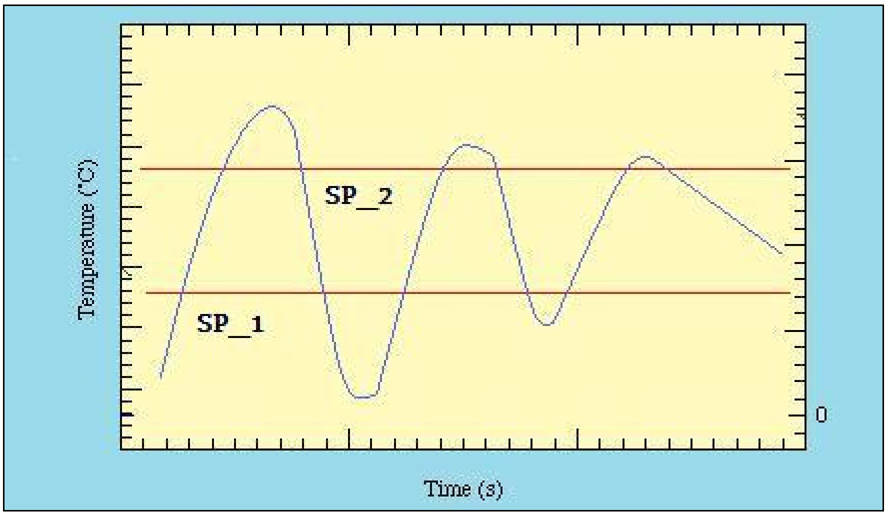


Figure 3.20 Hysteresis Characteristic Added On-Off Control Graphics

In this method, two different setpoint is defined to system by user. It means, a temperature interval is defined and system is try to protect this temperature interval. If temperature is less than set point 1 or between set point 1 and set point 2 in initial conditions, transistors are activated and heater panels are started to warm. If average temperature of the sensors exceed set point 2 value, transistors are deactivated. Transistors are not activated till average temperature value become less than set point 1. In this method activate- deactivate frequency of the batteries is less, so longer battery life is obtained according to the on-off control without hysteresis control.

3.3.3.1 Flow Chart of the System

Flow chart of the control system that is mentioned above given on Figure 3.25 and 3.26 below.

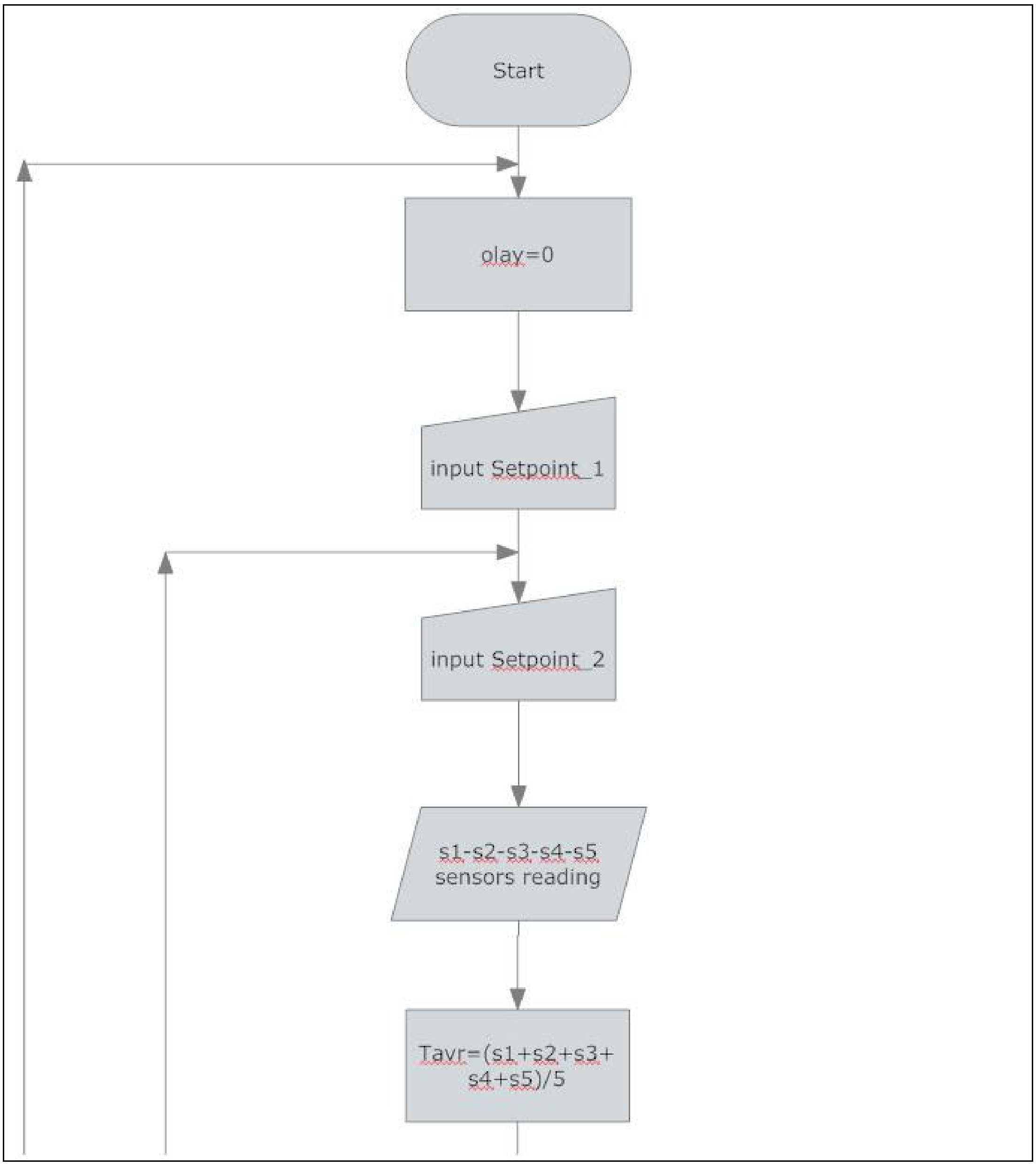


Figure 3.21 Flow Chart

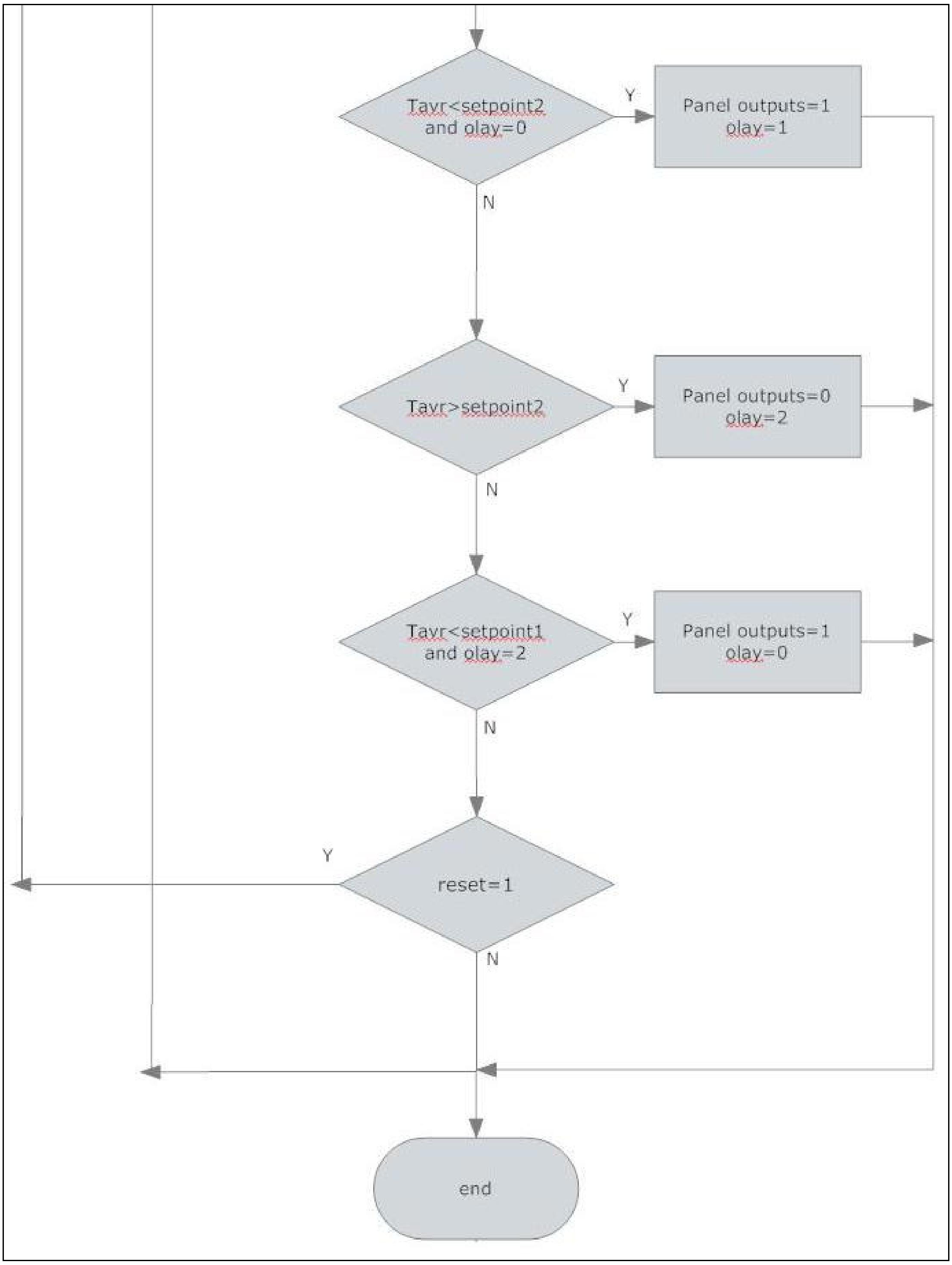


Figure 3.22 Flow Chart

3.2. Method

For heater panels, unit layer length is designed as 10cm length. During the pre-experiments, 1, 2, 3 and 4-ply heated panels made by steal threads had been integrated orderly as 1, 2, 3 and 4 pieces in to the system and totally heat behaviors of 16 different configurations had been observed. For this purpose, DS 1820 temperature sensors were fixed on to the panels with the help of tape-velcro. The experiment times had been limited with 60 minutes. Temperature values came from sensors had been recorded in this time period. Simultaneously, voltage amount had been measured that came from power source to system. If the power source broke down, the same values had been recorded for the time that measurements would be done.

Digital sensors, which had been purposed to observation of the panels thermal behaviors, attached to clothes and focused on to be contact closely with the skin surface. Therefore, starting temperature of the sensors had been assumed as surface temperature of the thermal model skin. Digital readers had been accepted with 0,1°C accuracy. It is suitable for usability on the system.

According to general configuration of the system, the values taken by temperature sensors can be evaluated by one of the measurement unit and working (on/off) of the system can be arranged with the help of the values that came from sensors. As a summary, the temperature levels, which heater clothes prototype will be active or passive, were obtained by bases of the data comes from temperature readers. But the purpose of obtaining working limits for system or especially for power source, working interval had been arranged in wide section during the experiments and also aimed that system worked continuously during the experiments.

Location of heater panels had been based for the location of the sensors on the clothes. These locations had been decided according to examinations on scientific researches and standards about heater clothes or similar applications. Measurements had been done according to located temperature sensors in different places for the zone of both front and back sides of the clothes prototype.

Zones for location of sensors are given in literatures;

- Front body; heart and liver zone, the both hand wrists and left muscle zone
- Rear body; nape zone, right shovel bone, kidney and right muscle zone

The clothes are designed as a waistcoat so it hadn't been done any measurements on muscle and wrist zones because these points directly contact with cold weather. For panels location zones had been organized according to follow explanation. On front zone, left and right sides of abdomen space and on rear zone, both kidney zones are selected. Consequently, to observe heat levels, also sensors had been located on these zones.

Adding to observation of temperature increasing, voltage and current amounts related to time had been followed up during the experiments. Voltage of power source, which produces voltage for supplying to the system, had been recorded. Also, current measurements had been done on heater panels to observe current amount that panels need. Therefore, it was purposed that electrical parameters can be followed for panels with different number of ply wrapped to an electronic circuit. With using the current and voltage parameters that had been given to system, energy calculations could be done by the way of Ohm Law;

"$Q = VIt$" (1)

where "V" refers to voltage, "I" refers to current and "t" refers to time. Volt.Amper.sn is obtained for Energy unit. So, all the calculated results had been obtained in Joule unit.

Applications of trying appropriate power sources/batteries, which supply current to panels on system, all experiments had been done with using the Ni-MH batteries with 12 V 3300mAh capacities. Especially, to remove weight problem of the power sources, Ni-MH battery group had been separated to 2 parts, these parts had been put in pocket on rear body of the clothes prototype. This solution helps to distribute the center of gravity and get comfort for users.

To avoid immovability of power sources on system, it was purposed to use different type of batteries. Also, it was a chance to take advantage with using different battery technologies. It is preferable to use light and small battery as possible as.

CHAPTER FOUR
RESEARCH RESULTS

4.1 Testing the Performance of the System

First of all, it was aimed to determine the electronic productivity of the substructure when testing the heater cloth prototype. For this purpose, at room temperature (22±1°C), some pre-trials were made and some data were got about performance of the system. In these trials, 1, 2, 3 and 4-ply heater panels were used. Some panel configurations are formed for the tests and voltage data were obtained about power supply. Resistive values of the heater panels are given in Table 4.1.

Table 4.1 Resistance values of the heater panels (Ω)

	Panel 1	**Panel 2**	**Panel 3**	**Panel 4**
1-ply	56	53	55	56
2-ply	26	27	25	25
3-ply	20	19	20	19
4-ply	15	14	14	14

Between Figure 4.1 and Figure 4.8, temperature and voltage data of 1 panel trials in different ply configurations are given.

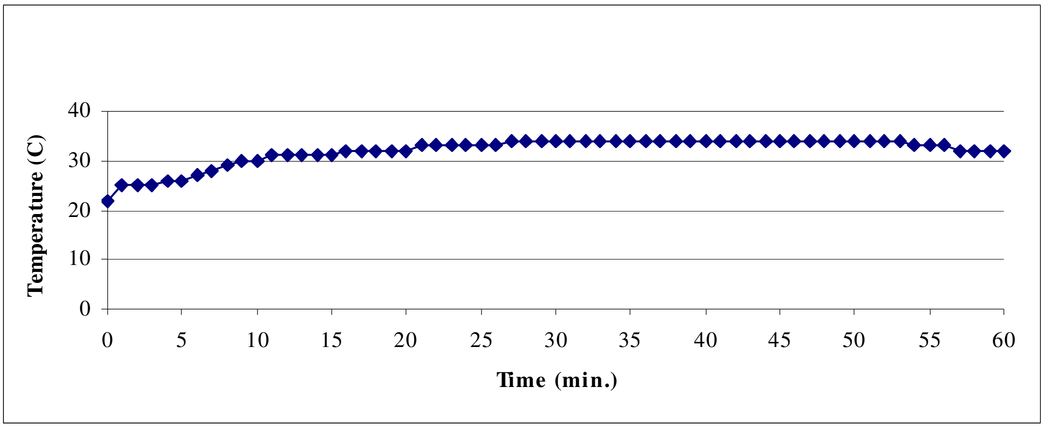


Figure 4.1 Temperature data of 1-ply, 1 panel trial

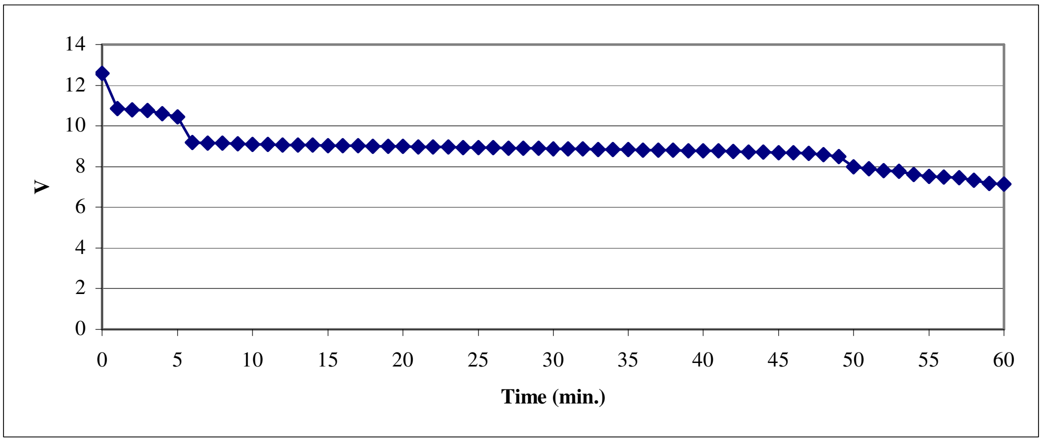


Figure 4.2 Voltage – time graphic of 1-ply, 1 panel trial

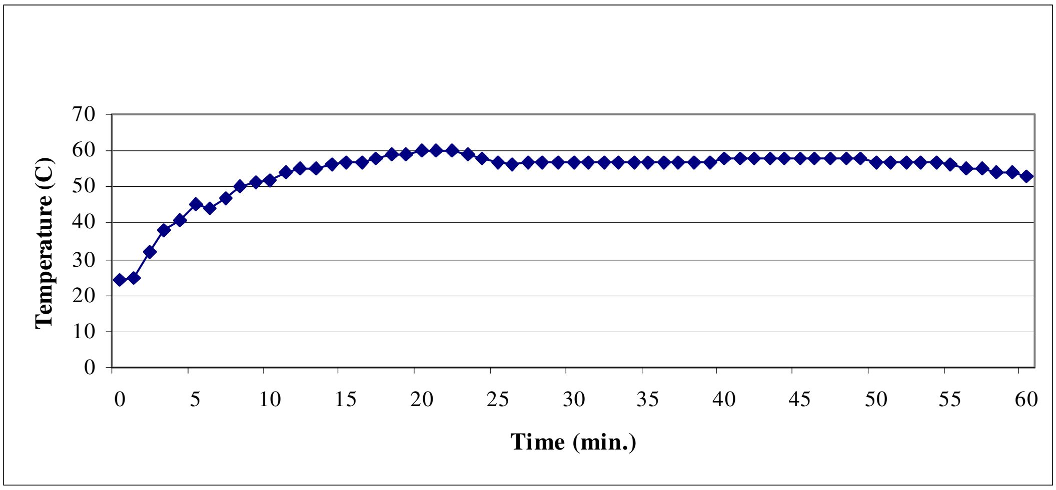


Figure 4.3 Temperature data of 2-ply, 1 panel trial

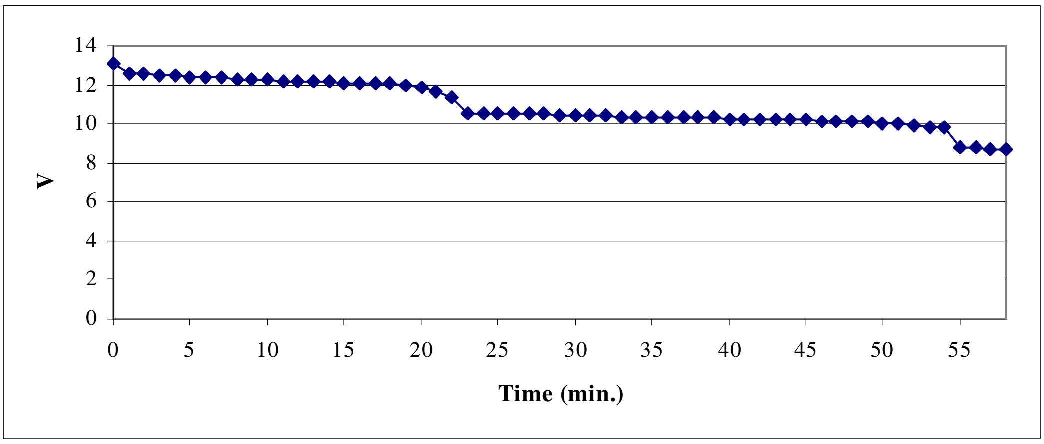


Figure 4.4 Voltage –time graphic of 2-ply, 1 panel trial

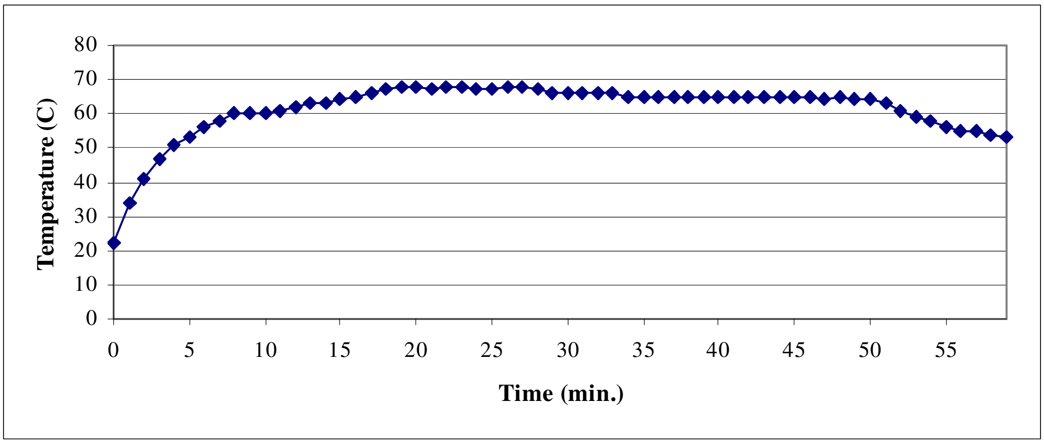


Figure 4.5 Temperature data of 3-ply, 1 panel trial

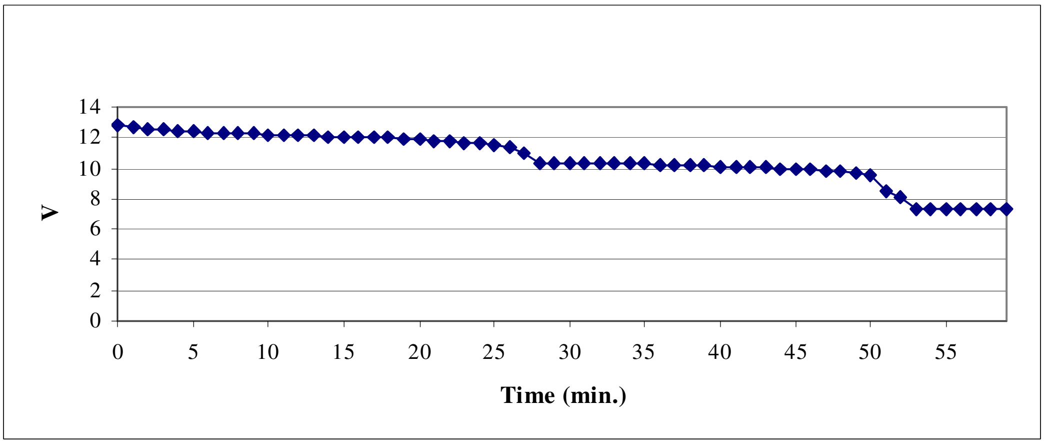


Figure 4.6 Voltage –time graphic of 3-ply, 1 panel trial

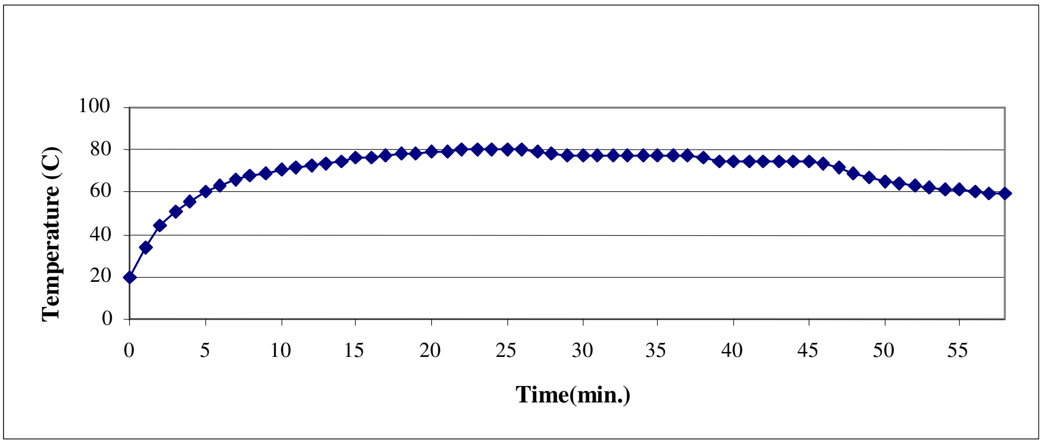


Figure 4.7 Temperature data of 4-ply, 1 panel trial

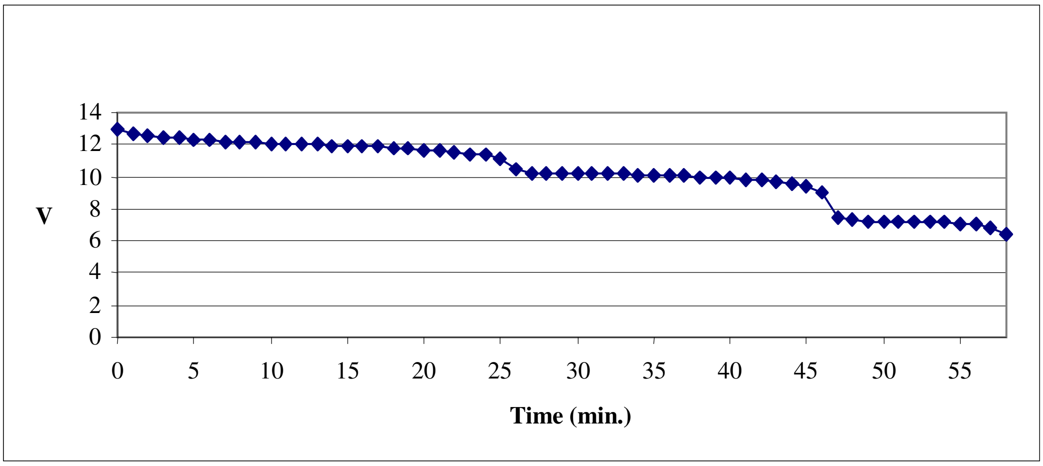


Figure 4.8 Voltage –time graphic of 4-ply, 1 panel trial

As shown in Figure 4.1 – 4.8, trials were realized for 60 minutes for all 1 panel trials. In 1-ply, 1 panel trial, approximately 15°C, in 2-ply, 1 panel trial, 40°C, in the same way, 3-ply – 1 panel trial, 50°C, 4-ply, 1 panel trial, 60°C temperature increases were obtained in temperatures of the heater panels.

Between Figure 4.9 and Figure 4.16, temperature and voltage data of 2 panels trials in different ply configurations are given.

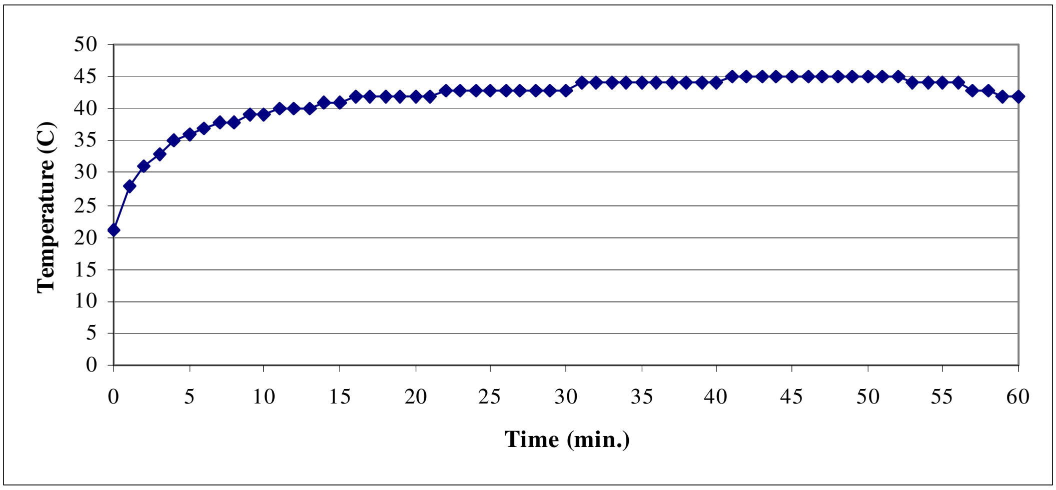


Figure 4.9 Temperature data of 1-ply, 2 panels trial

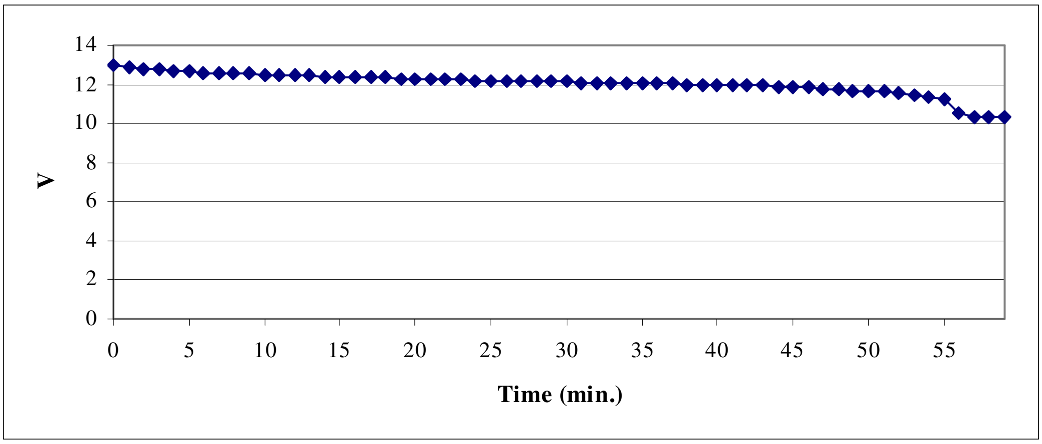


Figure 4.10 Voltage –time graphic of 1-ply, 2 panels trial

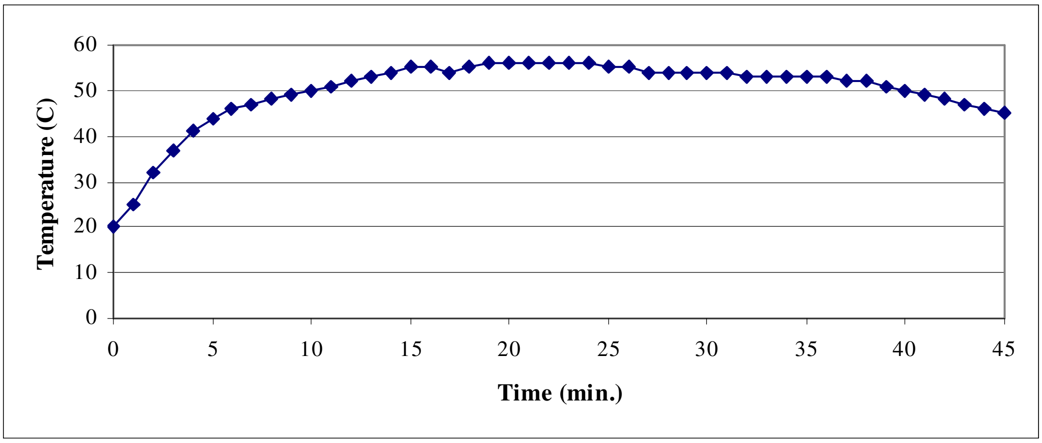


Figure 4.11 Temperature data of 2-ply, 2 panels trial

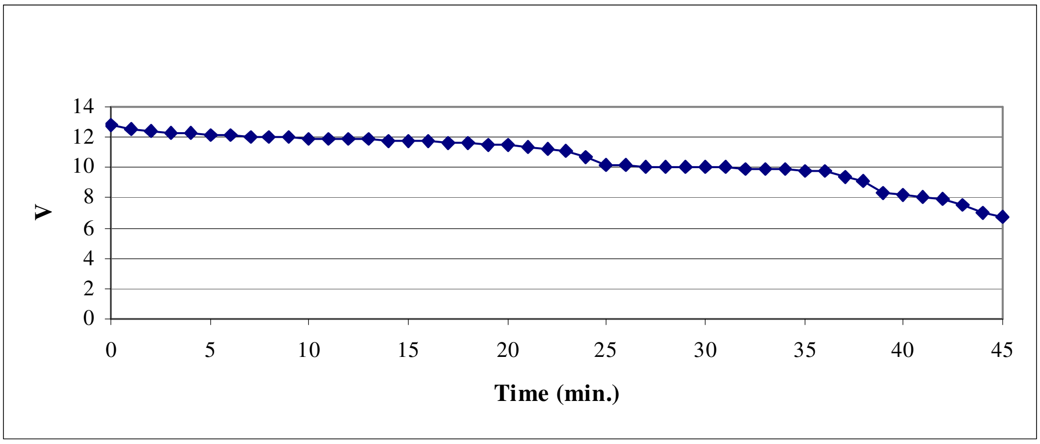


Figure 4.12 Voltage –time graphic of 2-ply, 2 panels trial

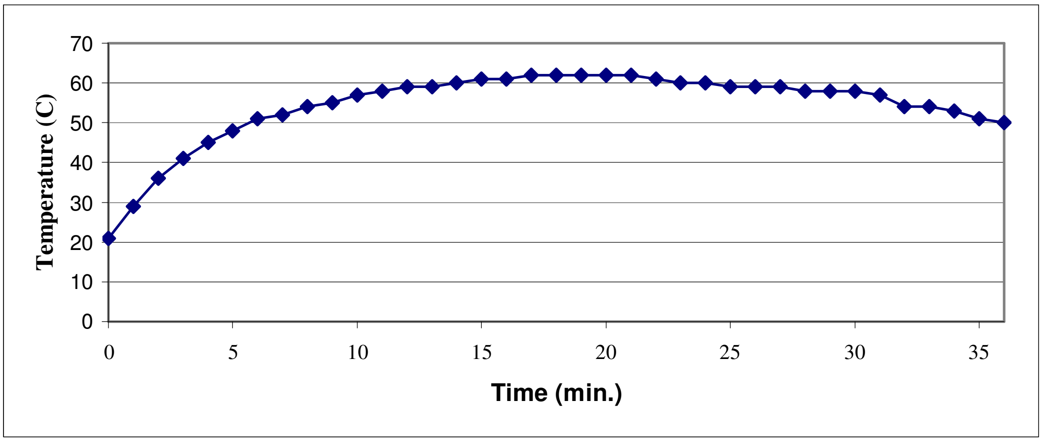


Figure 4.13 Temperature data of 3-ply, 2 panels trial

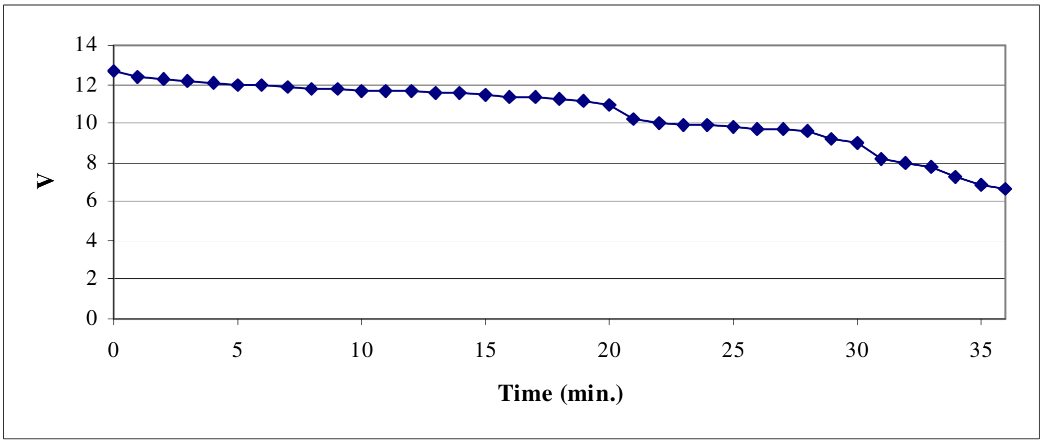


Figure 4.14 Voltage –time graphic 3-ply, 2 panels trial

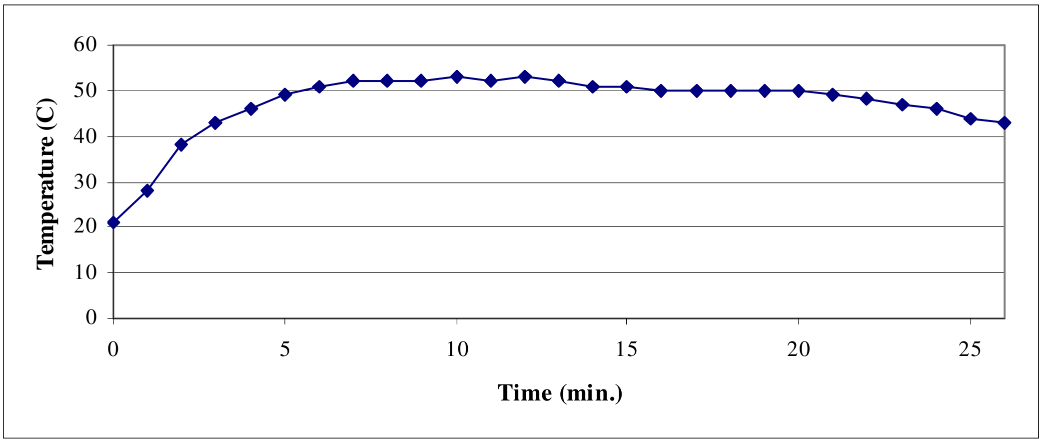


Figure 4.15 Temperature data of 4-ply, 2 panels trial

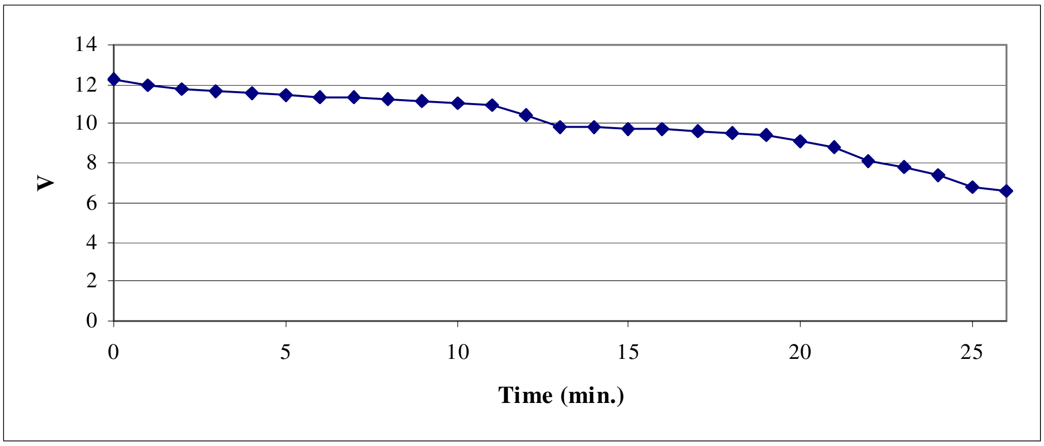


Figure 4.16 Voltage –time graphic of 4-ply, 2 panels trial

Graphics about 2 panels trials are shown in Figure 4.9 – 4.16, trials were realized for 60 minutes for 1-ply - 2 panels trial, measurement time decreased to 45 minutes in 2-ply, 2 panel trial, in 3-ply, 2 panels trial, it was 36 minutes and 4-ply, 2 panels trial, it was 26 minutes. In 1-ply, 2 panels trial, approximately 25^{o}C, 2-ply, 2 panel trial, 35^{o}C, in the same way, 3-ply, 2 panel trial, 40^{o}C, 4-ply, 2 panel trial, 30^{o}C temperature increases were obtained in temperatures of the panels.

Between Figure 4.17 and Figure 4.24, temperature and voltage data of the 3 panels trials are given.

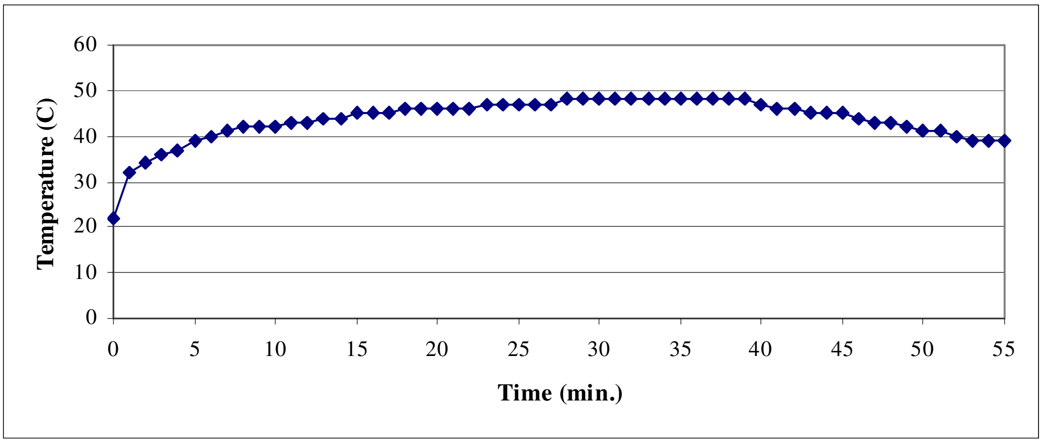


Figure 4.17 Temperature data of 1-ply, 3 panels trial

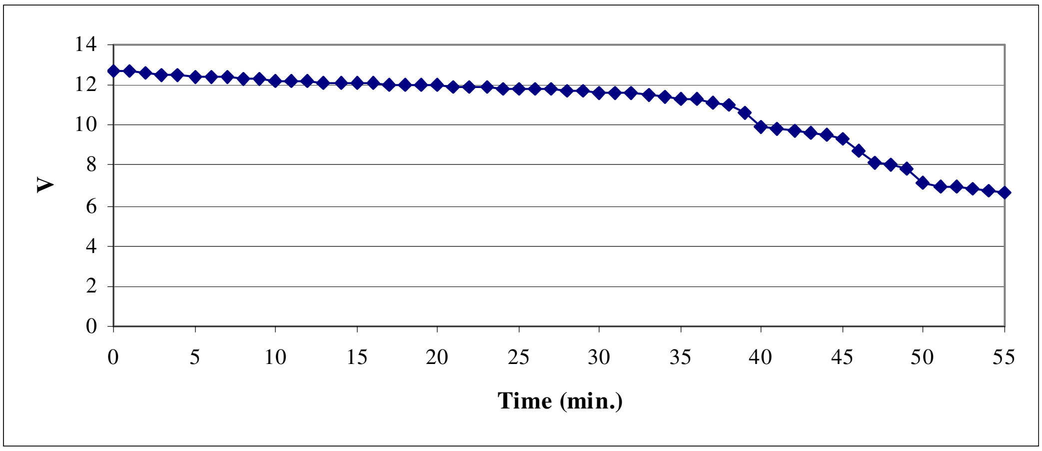


Figure 4.18 Voltage –time graphic of 1-ply, 3 panels trial

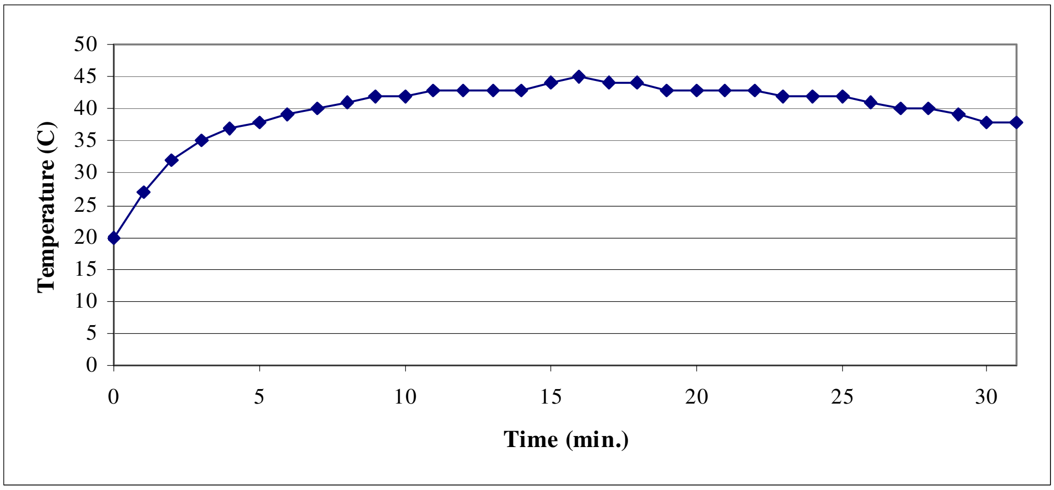


Figure 4.19 Temperature data of 2-ply, 3 panels trial

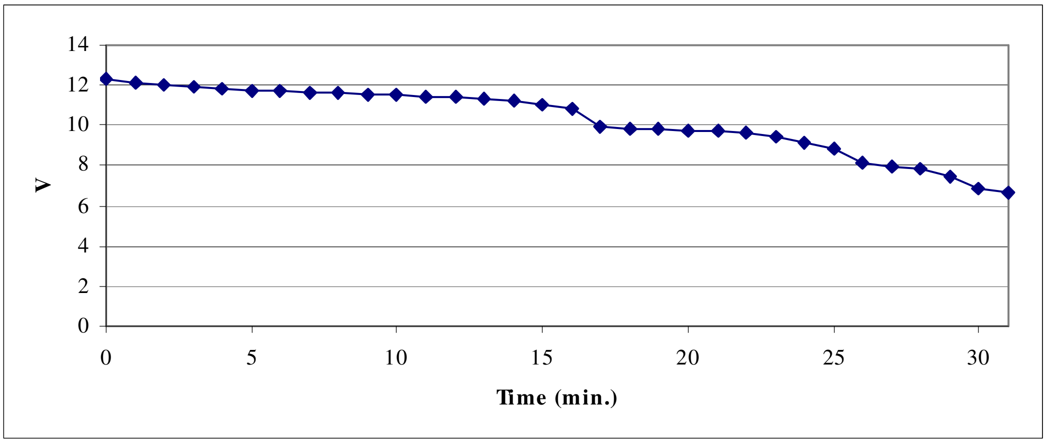


Figure 4.20 Voltage –time graphic of 2-ply, 3 panels trial

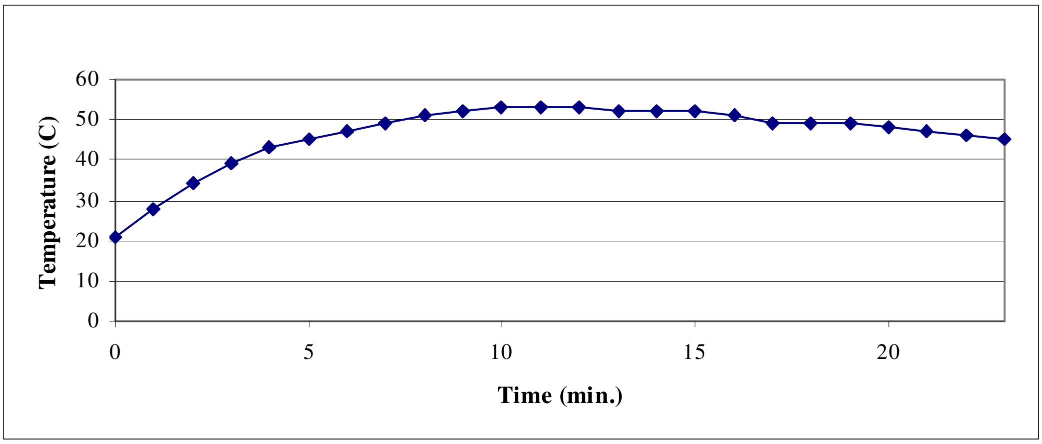


Figure 4.21 Temperature data of 3-ply, 3 panels trial

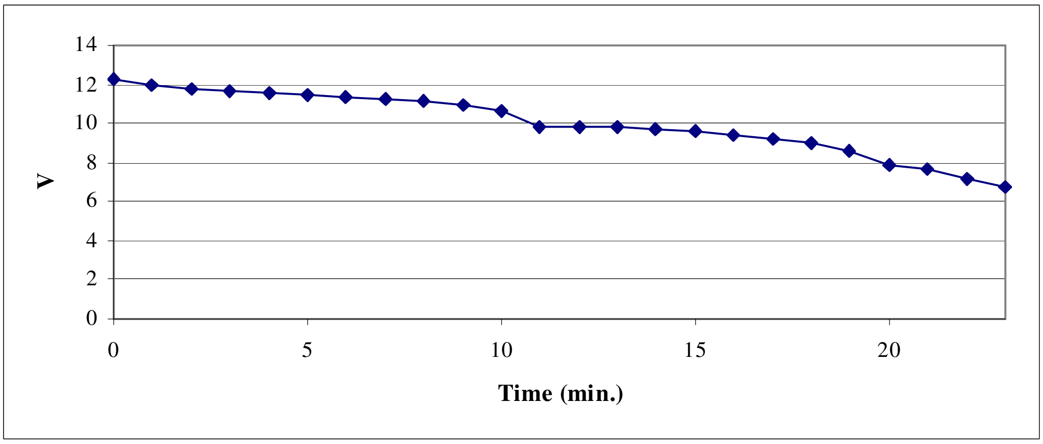


Figure 4.22 Voltage –time graphic of 3-ply, 3 panels trial

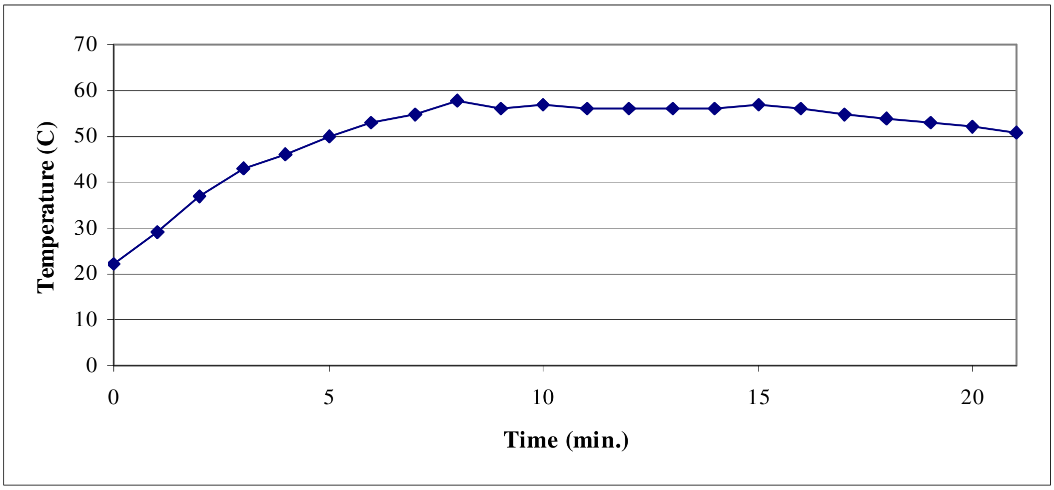


Figure 4.23 Temperature data of 4-ply, 3 panels trial

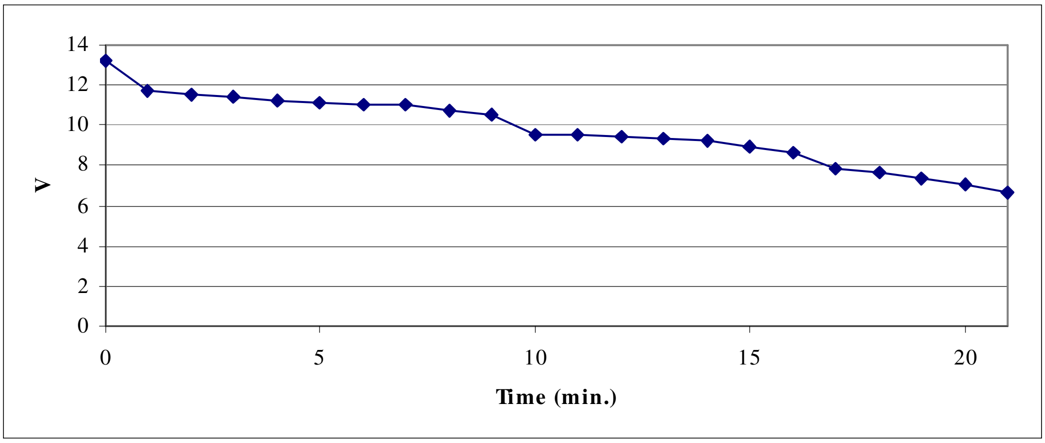


Figure 4.24 Voltage –time graphic of 4-ply, 3 panels trial

As shown in Figure 4.17 – Figure 4.24, in 3 panels trials, temperature of the panels was measured respectively during 55, 31, 23 and 21 minutes. Increase of temperature for 1-ply, 3 panels trials was approximately 15^{o}C, for 2-ply, 3 panels trial, it was approximately 40^{o}C, for 3-ply, 3 panels trial, it was approximately 50^{o}C, in 4-ply trial, it was approximately 60^{o}C.

Between Figure 4.25 and Figure 4.32, temperature and voltage data of 4 panels trials in different ply configurations are given.

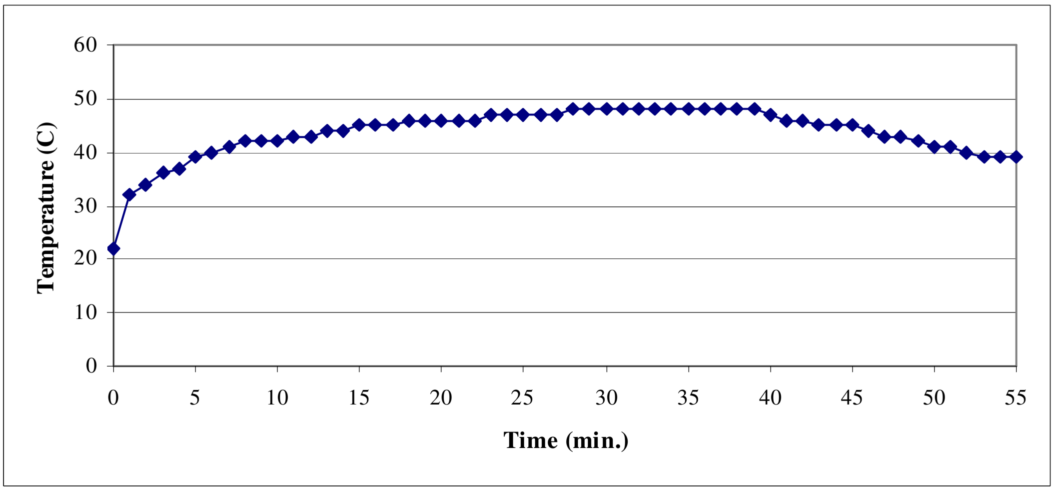


Figure 4.25 Temperature data of 1-ply, 4 panels trial

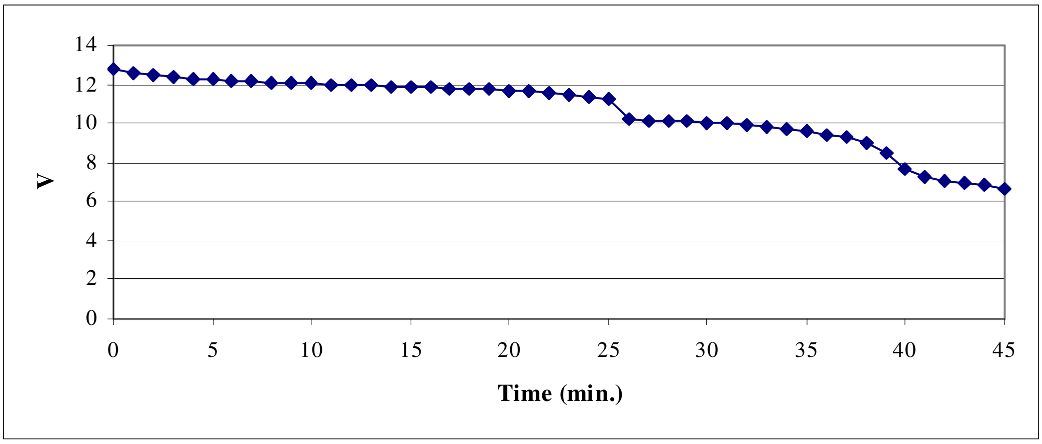


Figure 4.26 Voltage –time graphic 1-ply, 4 panels trial

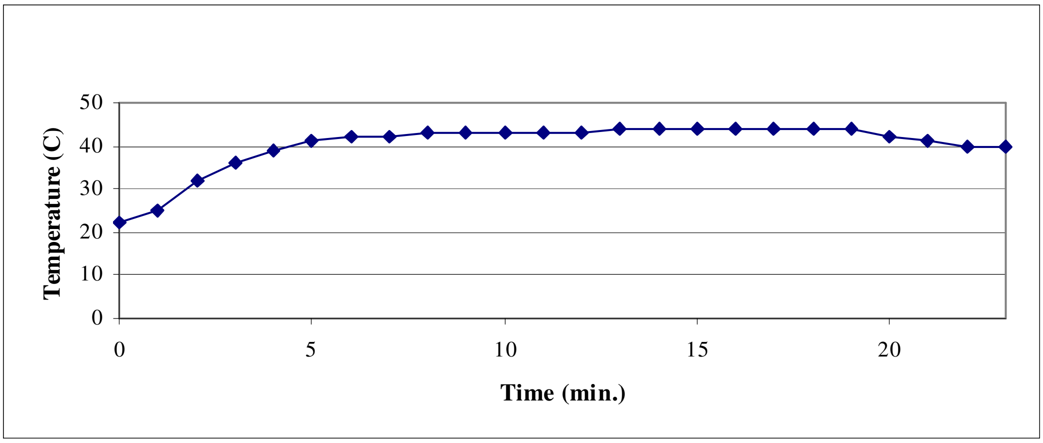


Figure 4.27 Temperature data of 2-ply, 4 panels trial

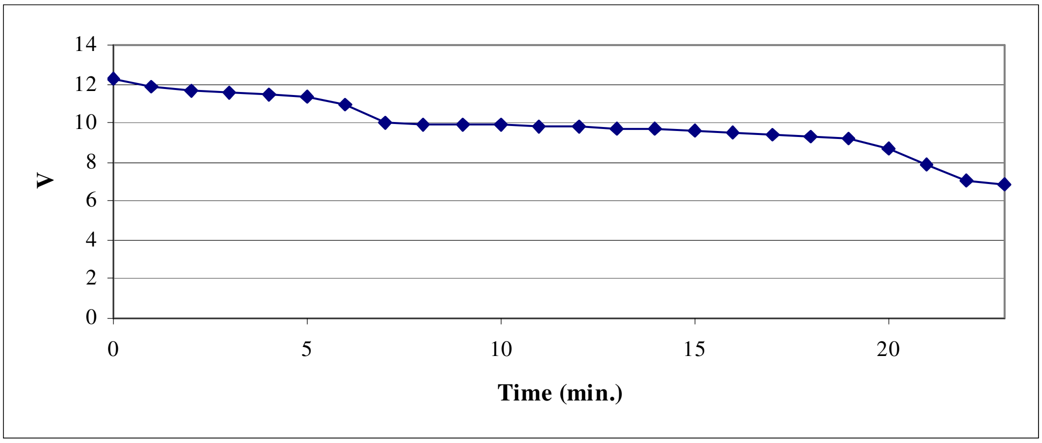


Figure 4.28 Voltage –time graphic of 2-ply, 4 panels trial

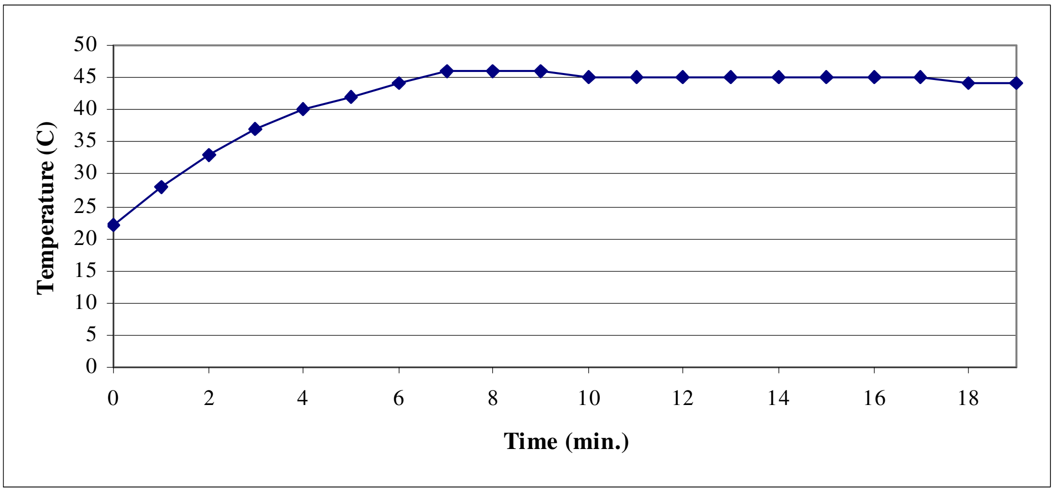


Figure 4.29 Temperature data of 3-ply, 4 panels trial

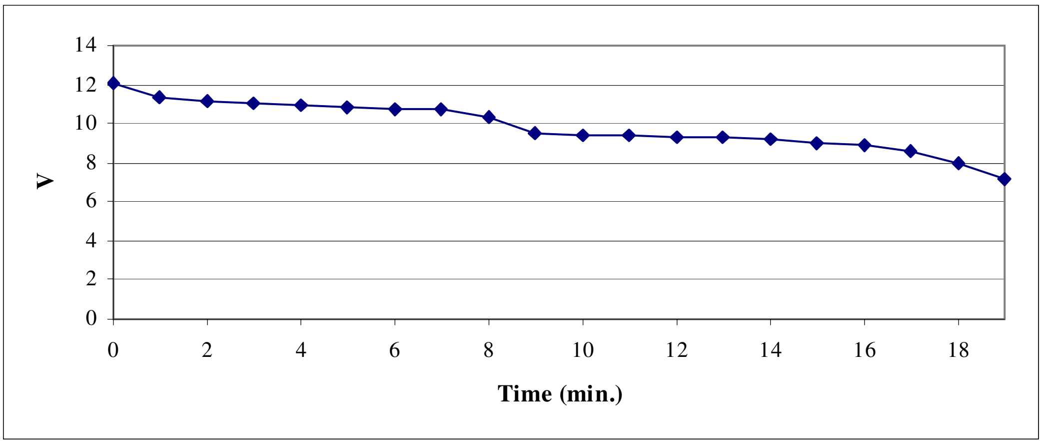


Figure 4.30 Voltage –time graphic of 3-ply, 4 panels trial

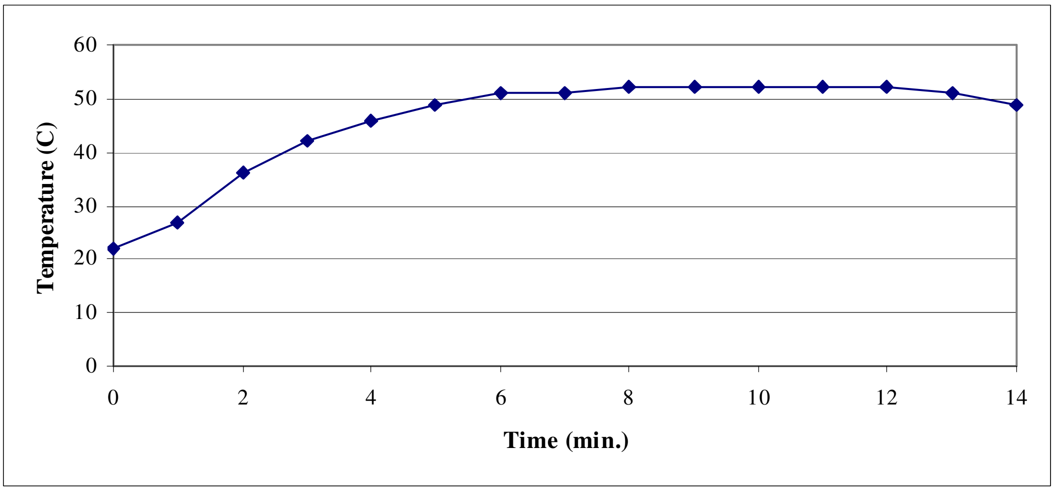


Figure 4.31 Temperature data of 4-ply, 4 panels trial

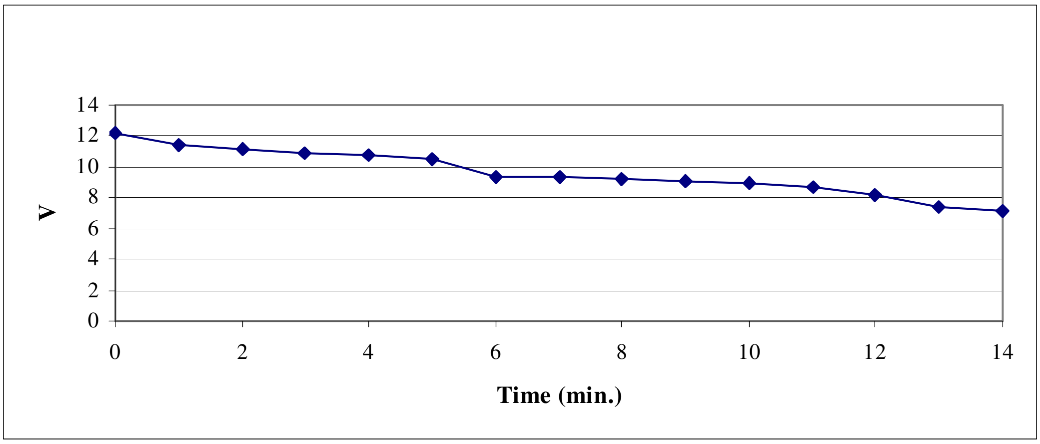


Figure 4.32 Voltage –time graphic of 4-ply, 4 panels trial

As shown in Figure 4.25 – Figure 4.32, in 4 panels trial, measurement times was also different from each others. In 1-ply, 4 panels trial, it was 45 minutes, on the other hand, increase in temperature of the panels were 15^{o}C. In 2-ply, 4 panels trials, it was 23 minutes, temperature increase in panels were 25^{o}C. When number of the ply increased to 3, it was 19 minutes, on the other hand, increase in temperature of panels was 28^{o}C. In 4-ply, 4 panels trials, it was 14 minutes, increase in temperature of panels was approximately 30^{o}C.

CHAPTER FIVE
CONCLUSIONS

Textile products have considerable places in our daily life. The idea of getting together and integrating textile products and mobile electronic circuits are starting point of the concept of electro-textiles. Development of computing systems and miniaturization of electrical end electronic materials have made easy to embed electronics and computing wearable devices to the textile materials such as pocket computers and mobile phones.

Electro-textiles are interacted with users and it can be called as "smart" because they can make some decisions and realize duties in some conditions. Instead of separating devices from their locations for example pockets, wearable electronic systems can be integrated into the textile product. This main approach describes the concept of intelligent textiles. So, a lot of scientists make researches on this subject at universities, research centers and has been succeed about integrating and embedding electronics with textile. Thanks to the computer technologies and improvement of mobile electronics, some electro-textiles were put on the market for practical use.

It is guessed that electro-textile for example smart clothes with heater function, will be the part of our daily life. It is very important that body temperature should be kept within a specified interval for personal physical performance. Environmental factors affect our live performance in positive or negative way. These effects have vital importance on lots of people who always works on open area just like soldiers, police, security forces, workers. Just as our body must be protected from warm effects, also we protect ourselves from cold effects.

In this research, electronic structures of electrically heated smart clothes is designed and realized for heater panels. are constructed by using conductive steel fiber in Dokuz Eylül University Textile Engineering Department. In the studies of designing and realizing the electronic structure, main purpose is to obtain optimum temperature increase and get maximum battery life and minimize electronic structure dimensions as much as possible. Optimum dimensions and optimum capacities of the batteries are considered. According to these considerations, Ni-MH battery configuration is constituted. Performance of the system is tested using these battery configurations. According to the electrical constitution, heater panels should have optimum resistance values for optimum heating. The fabrics, which have different layer quantities, show different warm-up characteristics because values of the resistance of panels are different from each others. Current consumptions of electronic circuit depend on electrical specifications of the heater panels. In this kind of applications, mobile power supply must be used. So life of the battery directly depends on resistance values of the heater panels.

Dimensions of heater fabric panels, number of plies and quantity of the conductive fibers should be determined correctly. In some conditions, two or more ply fabric constitutions should be used. Dimensions of the fabrics should be determined for the purpose of the usage. It is determined in associate study with Dokuz Eylül University Textile Engineering Department.

On this heater clothes prototype, as mentioned above, power supply is the most important factor on performance of the system. Capability of the batteries directly effect warming up and effective time of the system. Capability of the batteries is proportional with the dimensions of it. If we compare the batteries that are used on this research according to their dimensions, Ni-MH batteries are big, heavy and bulky. Tests are started with using 6V 3000mAh Ni-MH battery group. After realizing some tests, because of the resistance values of the heater panels, it is decided to use 12V 3300mAh battery group. After that, for optimum accommodation of the batteries on textile product, it is separate in two parts and connected serially with cables into the textile structure.

If we glance at the temperature observation, the maximum value had been obtained by using 4-layered 1-panel location in room temperature. In this trial, Ni-MH batteries were used and panel temperature has reached over $80^{o}C$. For temperature observation, the minimum value was obtained by using 1-ply, 4 panel trials at room temperature. Panel temperature was measured as 34°C.

If it is tried to compare effective time of the system into the room temperature trials, long application times are observed in 1 panel trials. 60 minutes effective lives of the battery are observed in these trials. If numbers of the plies of the heater panels are increased, it is observed that application times are decreased as it is estimated. In 2 panels trials, it was 40 minutes on average, in 3 panels trials, it was 30 minutes, in 4 panels trials, it decreases to 20 minutes on average.

In this research, hysteresis characteristic added on-off control method is applied. In on –off control method, the output signal from a controller is either FULL ON or FULL OFF it means completely on and completely off depending on the direction of the deviation from a set point. ON/OFF control action takes place if any deviation occurs from set point. This action responds quickly but it is sensitive to input noise which causes ON/OFF short intervals switching. This short interval switching causes more power consumption so it is decided to apply hysteresis characteristic on this control system. The aim of this operation is to decrease power consumption of the batteries so obtain longer application time, it means longer effective lives of the system.

For the future research, different kind of control method can be applied. As it is mentioned before, in on – off control method, the output signal is either full on or full off depending on the direction of the deviation from a set point. This full on and off action also increase power consumption of the battery. To avoid this, PWM control may be applied on this kin of system.

PWM control schemes are used in temperature controllers. PWM temperature controllers deliver power to heater panels by switching power either completely on or completely off similar with on - off control. This is usually done via a transistor similar with our system. The PWM output signal consists of a periodic square wave with a variable "on time" (Ton). This "on time", when expressed as a percentage of the period (P) of the square wave it is known as the duty cycle. Power to a heater panels is adjusted by varying the duty cycle of the square wave. Applying this method may be decrease power consumption of the system.

Another method that may be applied to this kind of system is PD (Proportional-Derivative) control method. In proportional (P) control, average heater power regulated and applied power is proportional to the error between sensor temperature and set-point (usually by time proportioning relay switching). If the derivative (D) characteristic is combined with proportional action, it improves control by sensing changes and correcting for them quickly. PD action is commonly used in general applications. Its use can help to minimize or even eliminate overshoot on system start up. So it may help us to decrease the power consumption also.

Another important task for the developed system is connection elements. In this project, traditional cables are used for the electrical and electronics connections which carry current from power source to heater panels, user surface, and digital temperature sensor to the circuit. For that purpose, in the future, conductor threads can be used for the transmission. And also, for the textile-electronic connection (between conductor threads and circuit components) can be done by hook and eye, button…etc, which are metallic basis textile materials. Adhesive conductor materials, which will be new generation products, can be used in the system instead of solder or something just like traditional connection materials. After that, in the body structure, textile basis material usage will increase and as a result, one step more development can be done as passing through electronic basis systems to textile basis systems.

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APPENDIX A: PIC BASIC CODES

```
'*****************************************************************
'*  Name    : TEMPCONT.BAS
'*  Author  : GURCAN KAHRAMAN
'*  Notice  : Copyright (c) 2006 [set under view...options]
'*          : All Rights Reserved
'*  Date    : 19.02.2006
'*  Version : 1.0
'*  Notes   :
'*          :

DEFINE LCD_EREG PORTD

col     var byte
row     var byte
key     var byte
key1    var byte
key2    var byte
minval  var byte
maxval  var byte
olay    var byte

DQ0     var portc.0
DQ1     var portc.1
DQ2     var portc.2
DQ3     var portc.3
count_remain0    var byte
count_remain1    var byte
count_remain2    var byte
count_remain3    var byte

count_per_c0     var byte
count_per_c1     var byte
count_per_c2     var byte
count_per_c3     var byte

temperature0 var word
temperature1 var word
temperature2 var word
temperature3 var word

temport      var word

maxpin     var    portd.0
minpin var    portd.1
```

```
olay = 0
   OPTION_REG.7 = 0

ADCON1 = 7              ' Make PORTA and PORTE digital
      Low PORTE.2             ' LCD R/W low (write)

      Pause 100               ' Wait for LCD to start
      Lcdout $fe, 1, "please give the"  ' Display sign on message
      LCDOut $fe,$c0, "temp. interval"
main:
'min değer
Gosub getkey
'-----------------hata
while key = 10 or key = 12
Lcdout $fe, 1, "invalid key"
LCDOut $fe,$c0, "try again"
pause 1500
gosub getkey
wend
'-----------------
key1=key
Lcdout $fe, 1, dec key1
pause 250
Lcdout $fe, 1
Gosub getkey
'-----------------hata
while key = 10 or key = 12
Lcdout $fe, 1, "invalid key"
LCDOut $fe,$c0, "try again"
pause 1500
gosub getkey
wend
'-----------------
minval=key1*10+key
Lcdout $fe, 1, dec minval, " : minimum value"
pause 1000
Lcdout $fe, 1
'max değer
Gosub getkey
'-----------------hata
while key = 10 or key = 12
Lcdout $fe, 1, "invalid key"
LCDOut $fe,$c0, "try again"
pause 1500
gosub getkey
wend
'-----------------
key1=key
```

```
            Lcdout $fe, 1, dec key1
            pause 250
            Lcdout $fe, 1
Gosub getkey
'-----------------hata
while key = 10 or key = 12
Lcdout $fe, 1, "invalid key"
LCDOut $fe,$c0, "try again"
pause 1500
gosub getkey
wend
'-----------------
maxval=key1*10+key
            Lcdout $fe, 1, dec maxval, " maximum value"
            pause 1000

        Lcdout $fe, 1, dec minval, " - ", dec maxval

mainloop:

temploop: OWOut DQ1, 1, [$CC, $44]        ' Start temperature conversion
          OWOut DQ2, 1, [$CC, $44]
          OWOut DQ3, 1, [$CC, $44]
          OWOut DQ0, 1, [$CC, $44]        ' Start temperature conversion

waitloop:
OWIn DQ1, 4, [count_remain1]
OWIn DQ2, 4, [count_remain2]
OWIn DQ3, 4, [count_remain3]
OWIn DQ0, 4, [count_remain3]

IF count_remain1 = 0 Then waitloop

'1. TEMPERATURE READING
OWOut DQ1, 1, [$CC, $BE]' Read the temperature
OWIn DQ1, 0, [temperature1.LOWBYTE, temperature1.HIGHBYTE, Skip 4, count_remain1,
count_per_c1]
temperature1 = (((temperature1 >> 1) * 100) - 25) + (((count_per_c1 - count_remain1) * 100) /
count_per_c1)

' 2. TEMPERATURE READING

OWOut DQ2, 1, [$CC, $BE]' Read the temperature
OWIn DQ2, 0, [temperature2.LOWBYTE, temperature2.HIGHBYTE, Skip 4, count_remain2,
count_per_c2]
temperature2 = (((temperature2 >> 1) * 100) - 25) + (((count_per_c2 - count_remain2) * 100)
/count_per_c2)
' 3. TEMPERATURE READING
```

```
OWOut DQ3, 1, [$CC, $BE]' Read the temperature
OWIn DQ3, 0, [temperature3.LOWBYTE, temperature3.HIGHBYTE, Skip 4, count_remain3,
        count_per_c3]
temperature3 = (((temperature3 >> 1) * 100) - 25) + (((count_per_c3 - count_remain3) * 100) /
        count_per_c2)

'4. TEMPERATURE READING
OWOut DQ0, 1, [$CC, $BE]' Read the temperature
OWIn DQ0, 0, [temperature0.LOWBYTE, temperature0.HIGHBYTE, Skip 4, count_remain0,
        count_per_c0]
temperature0 = (((temperature0 >> 1) * 100) - 25) + (((count_per_c0 - count_remain0) * 100) /
        count_per_c0)
temport = temperature1 + temperature2 +  temperature3 + temperature0

' WRITING TO THE LCD
LCDOut $fe, 1, DEC (temperature1 / 100) , dec (temperature2 / 100) , dec (temperature3 /
        100),dec (temperature0 / 100) ,dec (temport / 400)

if (temport / 400) < maxval and olay = 0 then

LCDOut $fe,$c0, "heating ..."
'LCDOut $fe,1, DEC (temperature / 100), "ISITIYOR"
high   portd.0
high   portd.1
high   portd.2
high   portc.4
high   portc.5

'high minpin
olay = 1
endif

if (temport / 400) > maxval then
low   portd.0
low   portd.1
low   portd.2
low   portc.4
low   portc.5

olay = 2
'low minpin
endif

if temport < minval and olay = 2 then
high   portd.0
high   portd.1
high   portd.2
```

```
high   portc.4
high   portc.5

'high minpin
olay = 0
endif

Pause 500
GoTo mainloop


' Subroutine to get a key from keypad
getkey:
        Pause 50                ' Debounce

getkeyu:
        ' Wait for all keys up
        PORTB = 0               ' All output pins low
        TRISB = $f0             ' Bottom 4 pins out, top 4 pins in
        If ((PORTB >> 4) != $f) Then getkeyu    ' If any keys down, loop

        Pause 50                ' Debounce

getkeyp:
        ' Wait for keypress
        For col = 0 to 3
                PORTB = 0
                TRISB = (dcd col) ^ $ff
                row = PORTB >> 4
                If row != $f Then gotkey
        Next col

        Goto getkeyp

gotkey: ' Change row and column to key number 1 - 16
        key = (col * 3) + (ncd (row ^ $f))
        if key = 11 then
        key = 0
        endif
        Return
```

APPENDIX B: DATASHEETS

MICROCHIP

PIC16F87X

28/40-Pin 8-Bit CMOS FLASH Microcontrollers

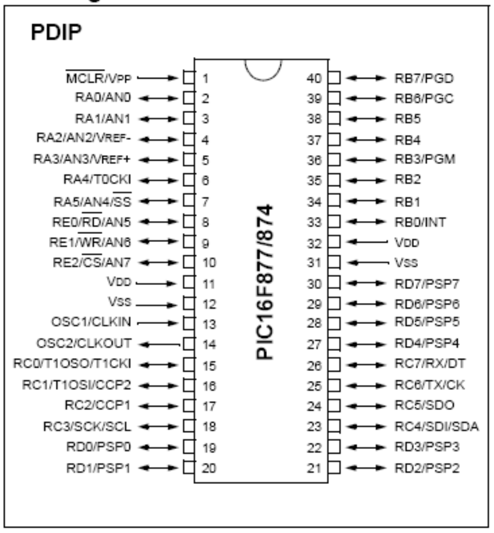
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial, Industrial and Extended temperature ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 µA typical @ 3V, 32 kHz
  - < 1 µA typical standby current

Pin Diagram



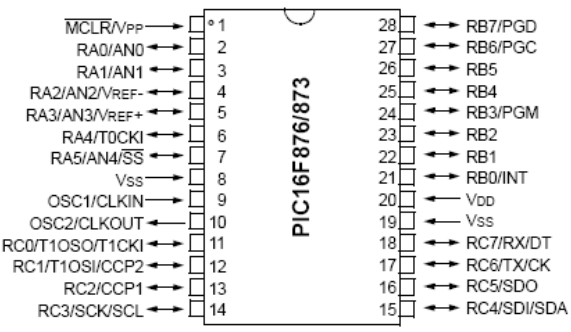
Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I^{2}C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

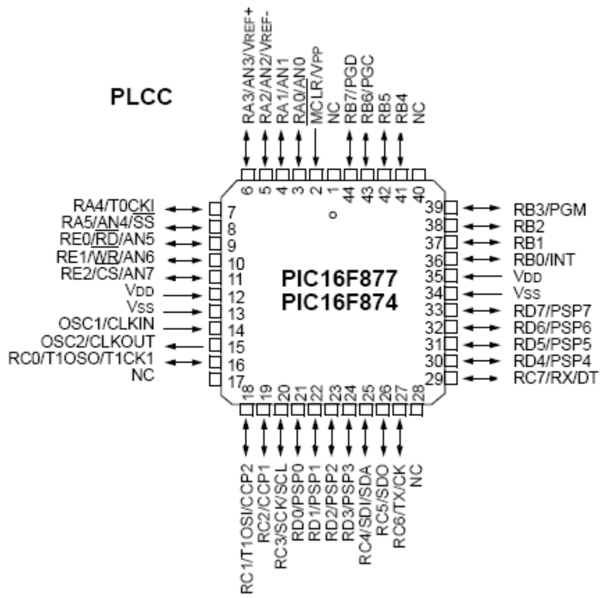
PIC16F87X

Pin Diagrams

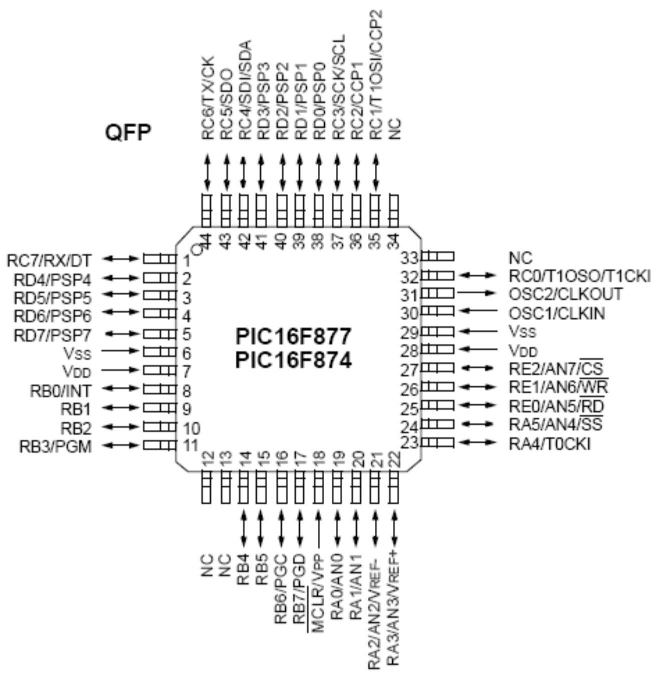
PDIP, SOIC



PLCC



QFP



1.0 DEVICE OVERVIEW

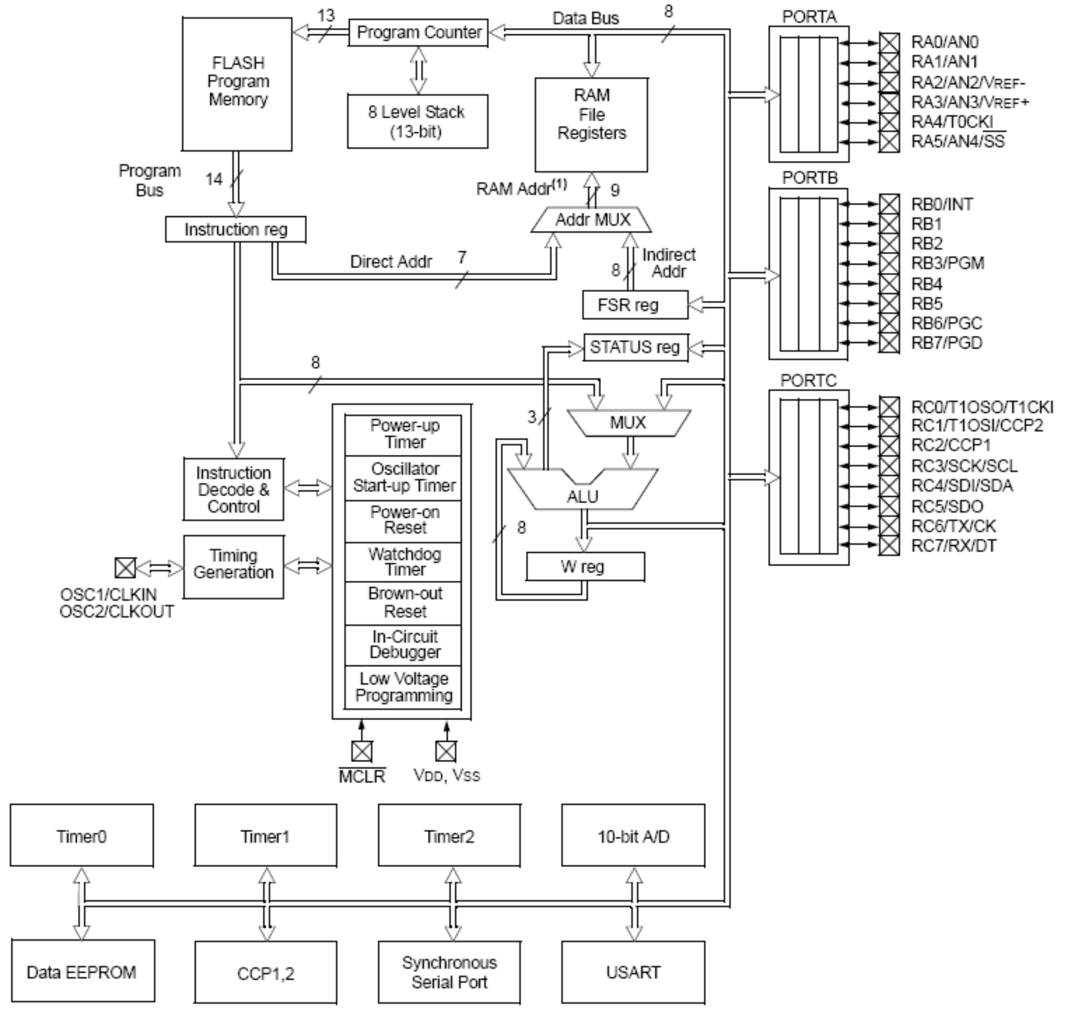
This document contains device specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

There are four devices (PIC16F873, PIC16F874, PIC16F876 and PIC16F877) covered by this data sheet. The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40-pin packages. The Parallel Slave Port is not implemented on the 28-pin devices.

The following device block diagrams are sorted by pin number; 28-pin for Figure 1-1 and 40-pin for Figure 1-2. The 28-pin and 40-pin pinouts are listed in Table 1-1 and Table 1-2, respectively.

FIGURE 1-1: PIC16F873 AND PIC16F876 BLOCK DIAGRAM

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes

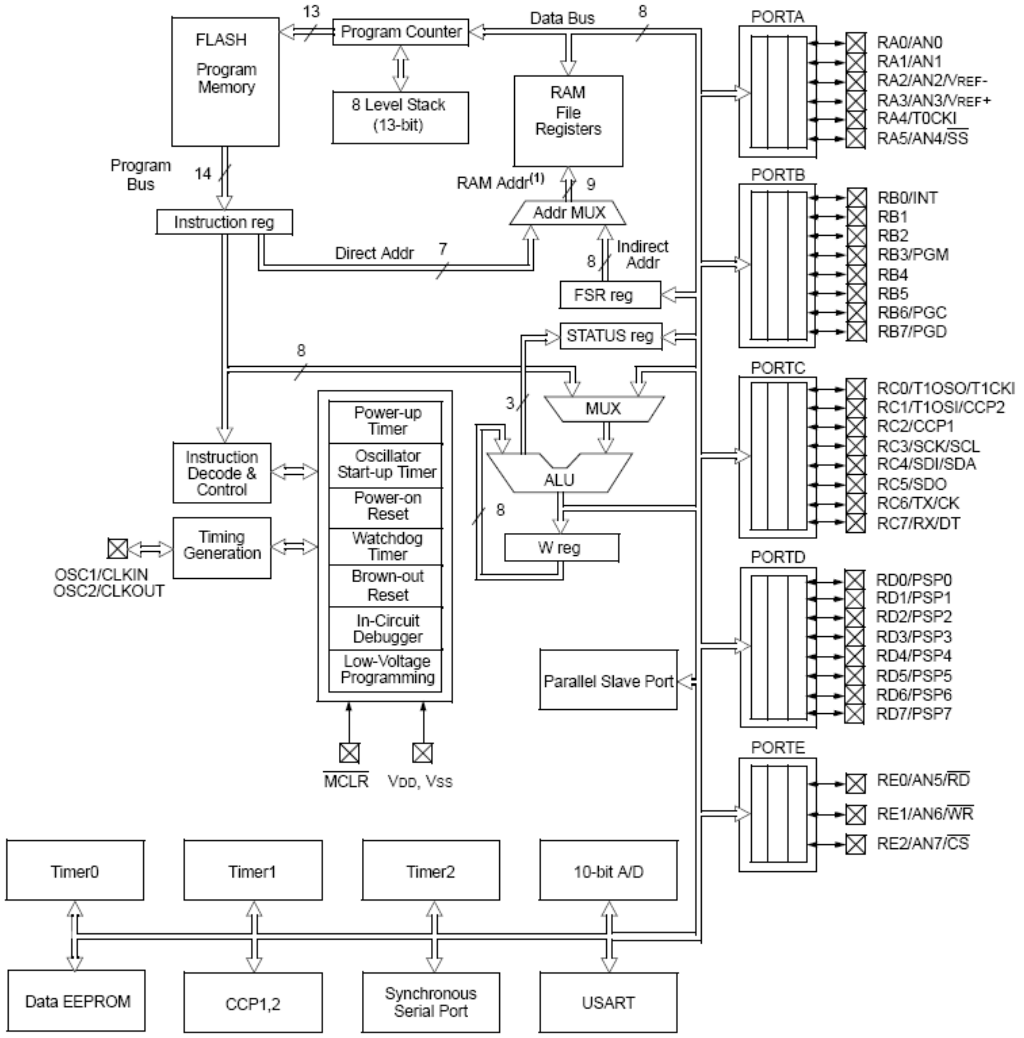


Note 1: Higher order bits are from the STATUS register.

PIC16F87X

FIGURE 1-2: PIC16F874 AND PIC16F877 BLOCK DIAGRAM

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

TABLE 1-1: PIC16F873 AND PIC16F876 PINOUT DESCRIPTION

Pin Name	DIP Pin#	SOIC Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	9	9	I	ST/CMOS(3)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	10	10	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, the OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/VPP	1	1	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
					PORTA is a bi-directional I/O port.
RA0/AN0	2	2	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	3	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/VREF-	4	4	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/VREF+	5	5	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	6	I/O	ST	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	7	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
					PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	21	21	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	22	22	I/O	TTL	
RB2	23	23	I/O	TTL	
RB3/PGM	24	24	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	25	25	I/O	TTL	Interrupt-on-change pin.
RB5	26	26	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	27	27	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	28	28	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.
					PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	11	11	I/O	ST	RC0 can also be the Timer1 oscillator output or Timer1 clock input.
RC1/T1OSI/CCP2	12	12	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	13	13	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/ PWM1 output.
RC3/SCK/SCL	14	14	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	16	16	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	17	17	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	18	18	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.
VSS	8, 19	8, 19	P	—	Ground reference for logic and I/O pins.
VDD	20	20	P	—	Positive supply for logic and I/O pins.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

PIC16F87X

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30	I	ST/CMOS(4)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/VPP	1	2	18	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/VREF-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/VREF+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	37	41	14	I/O	TTL	Interrupt-on-change pin.
RB5	38	42	15	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	39	43	16	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

DALLAS SEMICONDUCTOR

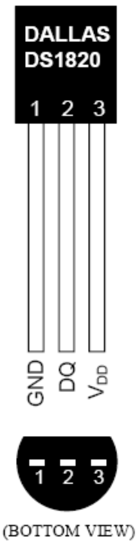
DS18S20 High Precision 1-Wire® Digital Thermometer

www.dalsemi.com

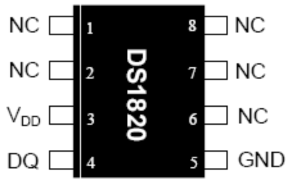
FEATURES

- Unique 1-wire interface requires only one port pin for communication
- Each device has a unique 64-bit serial code stored in an on-board ROM
- Multi-drop capability simplifies distributed temperature sensing applications
- Requires no external components
- Can be powered from data line. Power supply range is 3.0V to 5.5V
- Measures temperatures from –55°C to +125°C (–67°F to +257°F)
- ±0.5°C accuracy from –10°C to +85°C
- 9-bit thermometer resolution
- Converts temperature in 750 ms (max.)
- User-definable nonvolatile alarm settings
- Alarm search command identifies and addresses devices whose temperature is outside of programmed limits (temperature alarm condition)
- Applications include thermostatic controls, industrial systems, consumer products, thermometers, or any thermally sensitive system

PIN ASSIGNMENT



TO-92
(DS18S20)



8-pin 150-mil SOIC
(DS18S20Z)

PIN DESCRIPTION

GND - Ground
DQ - Data In/Out
V_{DD} - Power Supply Voltage
NC - No Connect

DESCRIPTION

The DS18S20 Digital Thermometer provides 9–bit centigrade temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18S20 communicates over a 1-wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. It has an operating temperature range of –55°C to +125°C and is accurate to ±0.5°C over the range of –10°C to +85°C. In addition, the DS18S20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply.

Each DS18S20 has a unique 64-bit serial code, which allows multiple DS18S20s to function on the same 1–wire bus; thus, it is simple to use one microprocessor to control many DS18S20s distributed over a large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment or machinery, and process monitoring and control systems.

DETAILED PIN DESCRIPTIONS Table 1

8-PIN SOIC*	TO-92	SYMBOL	DESCRIPTION
5	1	GND	**Ground.**
4	2	DQ	**Data Input/Output pin.** Open-drain 1-wire interface pin. Also provides power to the device when used in parasite power mode (see "Parasite Power" section.)
3	3	V_{DD}	**Optional V_{DD} pin.** V_{DD} must be grounded for operation in parasite power mode.

*All pins not specified in this table are "No Connect" pins.

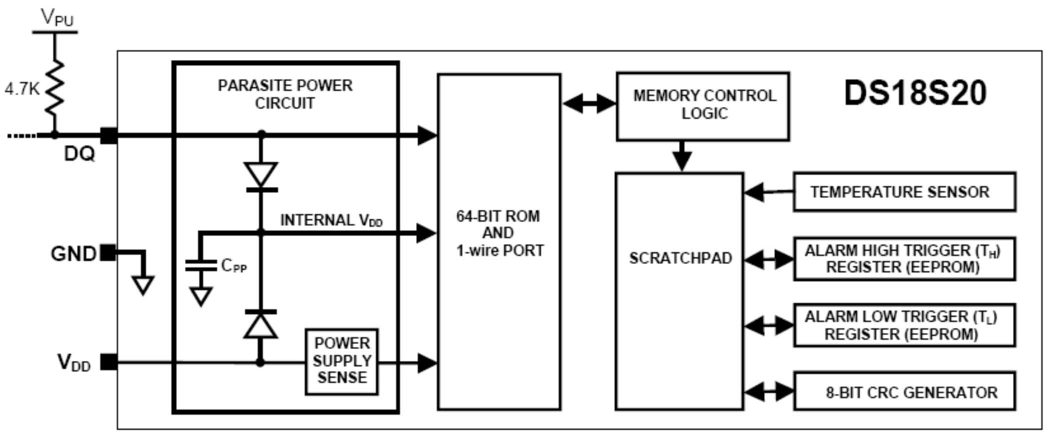
OVERVIEW

Figure 1 shows a block diagram of the DS18S20, and pin descriptions are given in Table 1. The 64-bit ROM stores the device's unique serial code. The scratchpad memory contains the 2-byte temperature register that stores the digital output from the temperature sensor. In addition, the scratchpad provides access to the 1-byte upper and lower alarm trigger registers (T_H and T_L). The T_H and T_L registers are nonvolatile (EEPROM), so they will retain data when the device is powered down.

The DS18S20 uses Dallas' exclusive 1-wire bus protocol that implements bus communication using one control signal. The control line requires a weak pullup resistor since all devices are linked to the bus via a 3-state or open-drain port (the DQ pin in the case of the DS18S20). In this bus system, the microprocessor (the master device) identifies and addresses devices on the bus using each device's unique 64-bit code. Because each device has a unique code, the number of devices that can be addressed on one bus is virtually unlimited. The 1-wire bus protocol, including detailed explanations of the commands and "time slots," is covered in the 1-WIRE BUS SYSTEM section of this datasheet.

Another feature of the DS18S20 is the ability to operate without an external power supply. Power is instead supplied through the 1-wire pullup resistor via the DQ pin when the bus is high. The high bus signal also charges an internal capacitor (C_{PP}), which then supplies power to the device when the bus is low. This method of deriving power from the 1-wire bus is referred to as "parasite power." As an alternative, the DS18S20 may also be powered by an external supply on V_{DD}.

DS18S20 BLOCK DIAGRAM Figure 1



OPERATION – MEASURING TEMPERATURE

The core functionality of the DS18S20 is its direct-to-digital temperature sensor. The temperature sensor output has 9-bit resolution, which corresponds to 0.5°C steps. The DS18S20 powers-up in a low-power idle state; to initiate a temperature measurement and A-to-D conversion, the master must issue a Convert T [44h] command. Following the conversion, the resulting thermal data is stored in the 2-byte temperature register in the scratchpad memory and the DS18S20 returns to its idle state. If the DS18S20 is powered by an external supply, the master can issue "read time slots" (see the 1-WIRE BUS SYSTEM section) after the Convert T command and the DS18S20 will respond by transmitting 0 while the temperature conversion is in progress and 1 when the conversion is done. If the DS18S20 is powered with parasite power, this notification technique cannot be used since the bus must be pulled high by a strong pullup during the entire temperature conversion. The bus requirements for parasite power are explained in detail in the POWERING THE DS18S20 section of this datasheet.

The DS18S20 output data is calibrated in degrees centigrade; for Fahrenheit applications, a lookup table or conversion routine must be used. The temperature data is stored as a 16-bit sign-extended two's complement number in the temperature register (see Figure 2). The sign bits (S) indicate if the temperature is positive or negative: for positive numbers S = 0 and for negative numbers S = 1. Table 2 gives examples of digital output data and the corresponding temperature reading.

Resolutions greater than 9 bits can be calculated using the data from the temperature, COUNT REMAIN and COUNT PER °C registers in the scratchpad. Note that the COUNT PER °C register is hard-wired to 16 (10h). After reading the scratchpad, the TEMP_READ value is obtained by truncating the 0.5°C bit (bit 0) from the temperature data (see Figure 2). The extended resolution temperature can then be calculated using the following equation:

$$TEMPERATURE = TEMP\_READ - 0.25 + \frac{COUNT\_PER\_C - COUNT\_REMAIN}{COUNT\_PER\_C}$$

Additional information about high-resolution temperature calculations can be found in Application Note 105: "High Resolution Temperature Measurement with Dallas Direct-to-Digital Temperature Sensors".

TEMPERATURE REGISTER FORMAT Figure 2

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
LS Byte	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^{-1}

	bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8
MS Byte	S	S	S	S	S	S	S	S

TEMPERATURE/DATA RELATIONSHIP Table 2

TEMPERATURE	DIGITAL OUTPUT (Binary)	DIGITAL OUTPUT (Hex)
+85.0°C*	0000 0000 1010 1010	00AAh
+25.0°C	0000 0000 0011 0010	0032h
+0.5°C	0000 0000 0000 0001	0001h
0°C	0000 0000 0000 0000	0000h
-0.5°C	1111 1111 1111 1111	FFFFh
-25.0°C	1111 1111 1100 1110	FFCEh
-55.0°C	1111 1111 1001 0010	FF92h

*The power-on reset value of the temperature register is +85°C

OPERATION – ALARM SIGNALING

After the DS18S20 performs a temperature conversion, the temperature value is compared to the user-defined two's complement alarm trigger values stored in the 1-byte T_H and T_L registers (see Figure 3). The sign bit (S) indicates if the value is positive or negative: for positive numbers S = 0 and for negative numbers S = 1. The T_H and T_L registers are nonvolatile (EEPROM) so they will retain data when the device is powered down. T_H and T_L can be accessed through bytes 2 and 3 of the scratchpad as explained in the MEMORY section of this datasheet.

T_H AND T_L REGISTER FORMAT Figure 3

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
S	2^6	2^5	2^5	2^5	2^2	2^1	2^0

Only bits 8 through 1 of the temperature register are used in the T_H and T_L comparison since T_H and T_L are 8-bit registers. If the result of a temperature measurement is higher than T_H or lower than T_L, an alarm condition exists and an alarm flag is set inside the DS18S20. This flag is updated after every temperature measurement; therefore, if the alarm condition goes away, the flag will be turned off after the next temperature conversion.

The master device can check the alarm flag status of all DS18S20s on the bus by issuing an Alarm Search [ECh] command. Any DS18S20s with a set alarm flag will respond to the command, so the master can determine exactly which DS18S20s have experienced an alarm condition. If an alarm condition exists and the T_H or T_L settings have changed, another temperature conversion should be done to validate the alarm condition.

POWERING THE DS18S20

The DS18S20 can be powered by an external supply on the V_{DD} pin, or it can operate in "parasite power" mode, which allows the DS18S20 to function without a local external supply. Parasite power is very useful for applications that require remote temperature sensing or that are very space constrained. Figure 1 shows the DS18S20's parasite-power control circuitry, which "steals" power from the 1-wire bus via the DQ pin when the bus is high. The stolen charge powers the DS18S20 while the bus is high, and some of the charge is stored on the parasite power capacitor (C_{PP}) to provide power when the bus is low. When the DS18S20 is used in parasite power mode, the V_{DD} pin must be connected to ground.

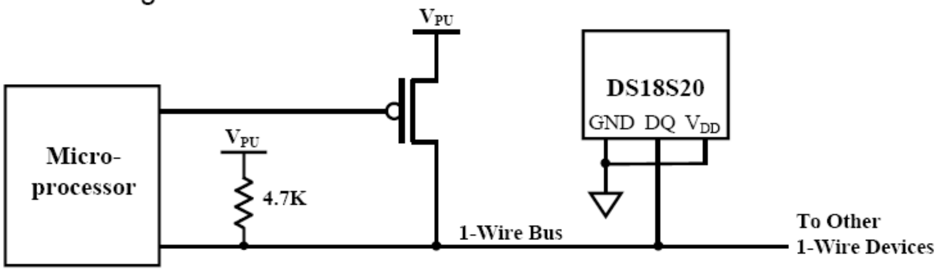
In parasite power mode, the 1-wire bus and C_{PP} can provide sufficient current to the DS18S20 for most operations as long as the specified timing and voltage requirements are met (refer to the DC ELECTRICAL CHARACTERISTICS and the AC ELECTRICAL CHARACTERISTICS sections of this data sheet). However, when the DS18S20 is performing temperature conversions or copying data from the scratchpad memory to EEPROM, the operating current can be as high as 1.5 mA. This current can cause an unacceptable voltage drop across the weak 1-wire pullup resistor and is more current than can be supplied by C_{PP}. To assure that the DS18S20 has sufficient supply current, it is necessary to provide a strong pullup on the 1-wire bus whenever temperature conversions are taking place or data is being copied from the scratchpad to EEPROM. This can be accomplished by using a MOSFET to pull the bus directly to the rail as shown in Figure 4. The 1-wire bus must be switched to the strong pullup within 10 µs (max) after a Convert T [44h] or Copy Scratchpad [48h] command is issued, and the bus must be held high by the pullup for the duration of the conversion (t_{conv}) or data transfer (t_{wr} = 10 ms). No other activity can take place on the 1-wire bus while the pullup is enabled.

The DS18S20 can also be powered by the conventional method of connecting an external power supply to the V_{DD} pin, as shown in Figure 5. The advantage of this method is that the MOSFET pullup is not required, and the 1–wire bus is free to carry other traffic during the temperature conversion time.

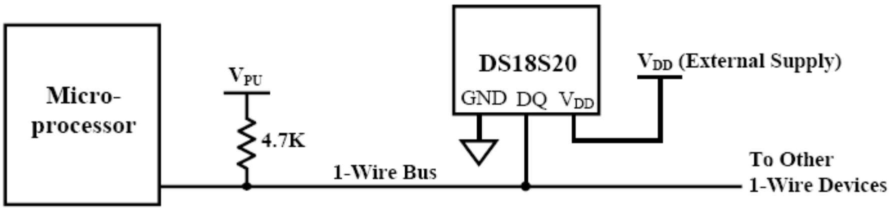
The use of parasite power is not recommended for temperatures above 100°C since the DS18S20 may not be able to sustain communications due to the higher leakage currents that can exist at these temperatures. For applications in which such temperatures are likely, it is strongly recommended that the DS18S20 be powered by an external power supply.

In some situations the bus master may not know whether the DS18S20s on the bus are parasite powered or powered by external supplies. The master needs this information to determine if the strong bus pullup should be used during temperature conversions. To get this information, the master can issue a Skip ROM [CCh] command followed by a Read Power Supply [B4h] command followed by a "read time slot". During the read time slot, parasite powered DS18S20s will pull the bus low, and externally powered DS18S20s will let the bus remain high. If the bus is pulled low, the master knows that it must supply the strong pullup on the 1-wire bus during temperature conversions.

SUPPLYING THE PARASITE-POWERED DS18S20 DURING TEMPERATURE CONVERSIONS Figure 4



POWERING THE DS18S20 WITH AN EXTERNAL SUPPLY Figure 5



64-BIT LASERED ROM CODE

Each DS18S20 contains a unique 64–bit code (see Figure 6) stored in ROM. The least significant 8 bits of the ROM code contain the DS18S20's 1–wire family code: 10h. The next 48 bits contain a unique serial number. The most significant 8 bits contain a cyclic redundancy check (CRC) byte that is calculated from the first 56 bits of the ROM code. A detailed explanation of the CRC bits is provided in the CRC GENERATION section. The 64–bit ROM code and associated ROM function control logic allow the DS18S20 to operate as a 1–wire device using the protocol detailed in the 1-WIRE BUS SYSTEM section of this datasheet.

64-BIT LASERED ROM CODE Figure 6

8-BIT CRC		48-BIT SERIAL NUMBER		8-BIT FAMILY CODE (10h)	
MSB	LSB	MSB	LSB	MSB	LSB

MOSPEC

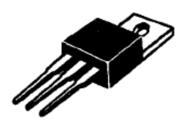
DARLINGTON COPLEMENTARY SILICON POWER TRANSISTORS

...designed for general-purpose amplifier and low speed switching applications

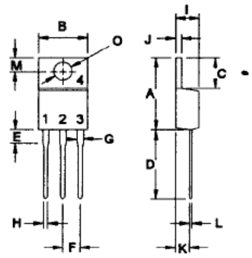
FEATURES:
* Collector-Emitter Sustaining Voltage-
  $V_{CEO(SUS)}$ = 45 V (Min) - BDX53,BDX54
  = 60 V (Min) - BDX53A,BDX54A
  = 80 V (Min) - BDX53B,BDX54B
  = 100 V(Min) - BDX53C,BDX54C
* Monolithic Construction with Built-in Base-Emitter Shunt Resistor

NPN	PNP
BDX53	BDX54
BDX53A	BDX54A
BDX53B	BDX54B
BDX53C	BDX54C

8 AMPERE
DARLINGTON
COMPLEMENTARY SILICON
POWER TRANSISTORS
45-100 VOLTS
60 WATTS



TO-220



PIN 1.BASE
2.COLLECTOR
3.EMITTER
4.COLLECTOR(CASE)

DIM	MILLIMETERS	
	MIN	MAX
A	14.68	15.31
B	9.78	10.42
C	5.01	6.52
D	13.06	14.62
E	3.57	4.07
F	2.42	3.66
G	1.12	1.36
H	0.72	0.96
I	4.22	4.98
J	1.14	1.38
K	2.20	2.97
L	0.33	0.55
M	2.48	2.98
O	3.70	3.90

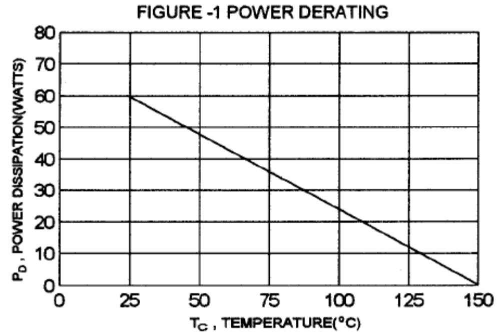
MAXIMUM RATINGS

Characteristic	Symbol	BDX53 BDX54	BDX53A BDX54A	BDX53B BDX54B	BDX53C BDX54C	Unit
Collector-Emitter Voltage	V_{CEO}	45	60	80	100	V
Collector-Base Voltage	V_{CBO}	45	60	80	100	V
Emitter-Base Voltage	V_{EBO}	5.0				V
Collector Current - Continuous Peak	I_C I_{CM}	8.0 12				A
Base Current	I_B	0.2				A
Total Power Dissipation @T_C = 25°C Derate above 25°C	P_D	60 0.48				W W/°C
Operating and Storage Junction Temperature Range	T_J, T_{STG}	-65 to +150				°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance Junction to Case	$R_{\theta jc}$	2.08	°C/W

FIGURE -1 POWER DERATING



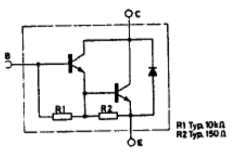
ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Sustaining Voltage(1) (I_C= 100 mA, I_B= 0)	BDX53, BDX54 BDX53A, BDX54A BDX53B, BDX54B BDX53C, BDX54C	$V_{CEO(sus)}$	45 60 80 100		V
Collector Cutoff Current (V_{CE}= 22 V, I_B= 0) (V_{CE}= 30 V, I_B= 0) (V_{CE}= 40 V, I_B= 0) (V_{CE}= 50 V, I_B= 0)	BDX53, BDX54 BDX53A, BDX54A BDX53B, BDX54B BDX53C, BDX54C	I_{CEO}		0.5 0.5 0.5 0.5	mA
Collector-Base Cutoff Current (V_{CB}= Rated V_{CB}, I_E= 0)		I_{CBO}		200	uA
Emitter-Base Cutoff Current (V_{EB}= 5.0 V, I_C= 0)		I_{EBO}		2.0	mA
ON CHARACTERISTICS (1)					
DC Current Gain (I_C= 3.0 A, V_{CE}= 3.0 V)		hFE	750		
Collector-Emitter Saturation Voltag (I_C= 3.0 A, I_B= 12 mA)		$V_{CE(sat)}$		2.0	V
Base-Emitter Saturation Voltage (I_C= 3.0 A, I_B= 12 mA)		$V_{BE(sat)}$		2.5	V
Diode Forward-Voltage (I_F= 3.0 A)		V_F		2.5	V

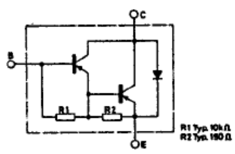
(1) Pulse Test: Pulse Width =300 us,Duty Cycle ≤ 2.0%

INTERNAL SCHEMATIC DIAGRAM

BDX53 Series NPN

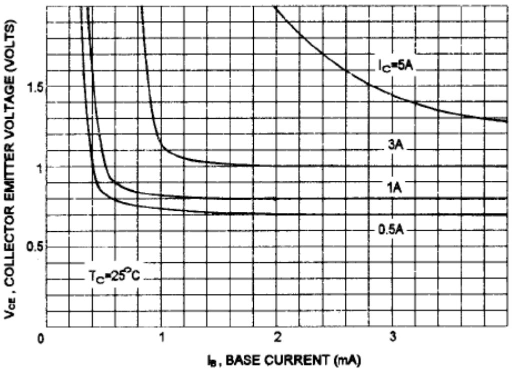


BDX54 Series PNP

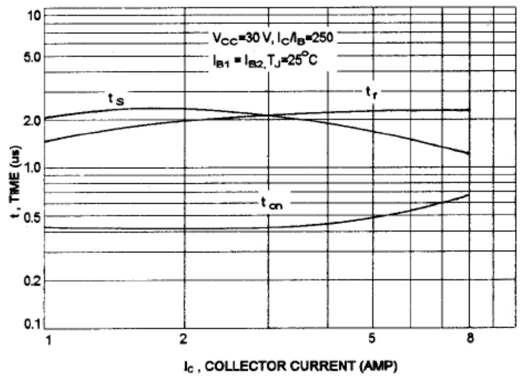


NPN BDX53,A,B,C

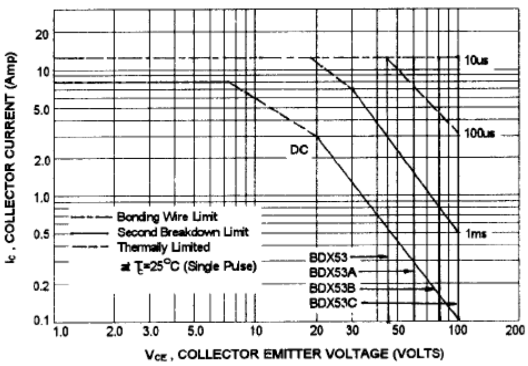
COLLECTOR SATURATION REGION



SWITCHING TIME

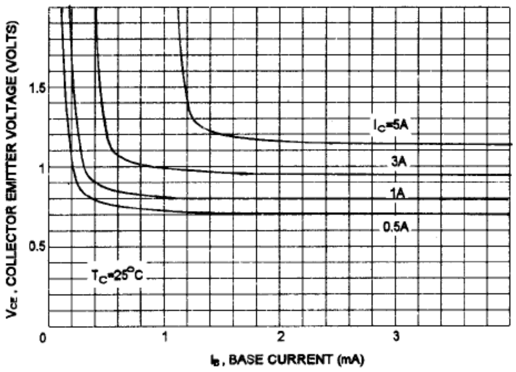


SAFE OPERATING AREA

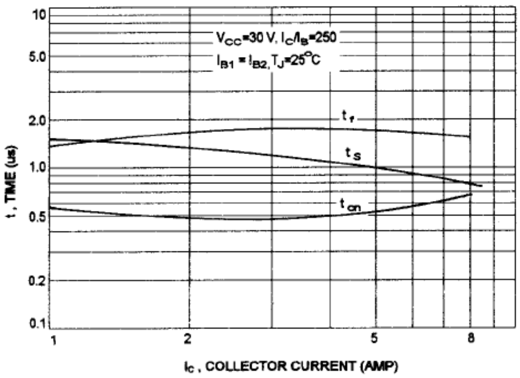


PNP BDX54,A,B,C

COLLECTOR SATURATION REGION



SWITCHING TIME



SAFE OPERATING AREA