Review

The Higher Technical Institute

Number 28 September 1999, Nicosia Cyprus

The Higher Technical Institute (HTI) was established in 1968 as a Government of Cyprus project with assistance by the United Nations Special Fund (UNDP) the United Nations-Education-Scientific and Cultural Organisation (UNESCO) and the International Labour Office (ILO). Cyprus Government Executing Agency: The Ministry of Labour and Social Insurance.

Review

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Various HTI Activities

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1999 HTI Graduation Ceremony

The Higher Technical Institute held its 29th Graduation Ceremony on Friday, 2 July 1999 at the Cyprus International Conference in Nicosia.

The President of the Republic, Mr Glafcos Clerides, attended the ceremony and awarded the Presidential Prize of £2000.00 to Mr George Papageorgiou, the graduate with the highest overall performance. Additionally, the President awarded a prize of £1000 from his personal budget to Fawwaz A. Kh. El Raie, the graduate with the highest overall performance from the Marine Engineering Department.

The Minister of Labour and Social Insurance Mr Andreas Moushouttas, who also attended the Ceremony,proceeded with the award of the diplomas to the one-hundred and fifty-five graduates while the HTI Director awarded the prizes sponsored by organisations and professional bodies to the graduates who excelled in their academic studies.

The Ceremony was also attended by the Acting Director General of the Ministry of Labour and Social Insurance Mr S. Soteriou, the Greek Ambassador Mr K. Rodousakis, members of the Parliament, other members of the Diplomatic Corps, government officials representatives of the political parties, trade unions and professional bodies.

The President of the Student Union, Mr Emilios Rotsides, addressed the gathering and highlighted the students' efforts and demands for professional recognition and restructuring of the Higher Technical Institute.

The main speaker was the HTI Director who thanked the dignitaries and all those who attended the Ceremony. His speech is as follows:

Your Excellency Mr President of the Republic,

On behalf of the Ministry of Labour and Social Insurance, the Higher Technical Institute and to-day's Graduating Students, I would like to thank you for honouring us with your presence at the twenty-ninth Graduation Ceremony of the HTI.

We consider your presence at our

Ceremony as a proof of your interest in the HTI.

I would also like to thank the rest of our guests who honour us with their presence at to-day's Ceremony.

This year 115 gentlemen and 40 ladies from our three-year full-time courses namely, 49 Electrical, 29 Mechanical, 14 Marine and 40 Civil Engineering students and 23 in Computer Studies are graduating.

Apart from the full-time courses, the HTI has also organised, various short courses with a total of 238 participants in the context of Continuous Professional Development, in co-operation with the Industrial Training Authority of Cyprus and various Professional Bodies.

It is well known that the HTI was established in 1968 on the basis of a 5-year Program of the Government of Cyprus with the assistance of the United Nations Development Program (UNDP), UNESCO and the International Labour Office (ILO). So this is the thirtieth Academic Year since the establishment of the HTI.

We have given a total of 3954 Graduates to the Cyprus Industry. It is a fact that a large number of HTI graduates have proceeded to various universities in the United Kingdom and the United States and obtained University qualifications. This proves that the HTI is not an educational establishment leading to a dead-end but it can be a step to further education.

However, many employers prefer the recruitment of HTI graduates recognising the fact that our Diploma has a value in itself.

Regarding the Graduates of the HTI who have decided to make their living armed with only their HTI Diploma, it is hoped that soon their endeavours for professional recognition will have a fruitful outcome both in Government and Semi - Government service as well as in the private sector.

The negative factors arising from the lack of professional recognition, including last year's student unrest, have had a negative effect on the interest shown in the HTI by candidates taking this year's entrance examinations for the various Institutions and Universities in Greece and Cyprus.

However, with the voting of the Law Bill regarding the operation of the HTI by the House of Representatives which should take place this month, it is hoped that it will signal a new start for the HTI.

As far as the infrastructure of the HTI is concerned, we are proceeding with the construction of an 800 seat sports hall with international specifications. Hopefully, it should be completed by September and it will be instrumental in enhancing our sporting and cultural activities.

Equipmentwise, from 1997 to 1999 we have spent about £750.000 on laboratory and workshop equipment and by the year 2000 we will

have spent about £1.500.000 on computers, associated equipment and software.

In the meantime, the HTI continues to offer an excellent training to its students and, in addition, is trying hard to participate in research programs financed by the European Union.

Furthermore, the HTI continues to offer its services to industry in consulting work as well as material testing.

Before finishing my Graduation speech I would like to thank the various industries, organisations as well as individuals for the various donations, scholarships and prizes given to us this year. Their names appear in the Graduation Ceremony Booklet (in the Program).

I would also like to express special thanks to his Excellency the President of the Republic for the £2000 Presidential Prize which is awarded to the best graduating student.

Finishing my speech I would like to wish, on behalf of the Ministry of Labour and Social Insurance and the Government, to today's graduating students progress in life and a successful career.

EDUCATIONAL ACTIVITIES

The Department of Civil Engineering in collaboration with the Industrial Training Authority and the Joint Group of Civil and Mechanical Engineers, organised a short course of 33 hours duration between September 22 and October 29 on "Earthquake Engineering". The course was presented by Dr Christis Chrysostomou.

The Department of Computer Studies of HTI in collaboration with the Cyprus Computer Society and the Industrial Training Authority organised a programme on "Hands-on-Year 2000: Options, Risks and Solutions" from 20-22 October 1998.

Educational Courses and Staff Training

Mr P Hadjimichael, Electrical Instructor attended a short course on "Use and Installation of Fibre Optic Cables" that was organised by the City University between 21-24 September 1998.

Dr L Lazari, Lecturer of the Mechanical Engineering Department, attended a short course on "Computer Aided Manufacturing" that was organised by the Manchester University between 2-6 November 1998.

STAFF EXCHANGES BETWEEN HTI & UNIVERSITIES/POLYTECHNICS ABROAD

Mr Ch Chrysafiades, Senior Lecturer, visited the University of Surrey from 23-27 November, 1998.

Mr A Kkolos, Lecturer, visited the City University from 2-6 November 1998.

Mr P. Pelecanos, Lab Assistant, visited the University of Glamorgan between 2-6 November 1998.

Mr G Katodrytis, Lecturer visited the University of Brunel between 2-6 November 1998.

Conferences and Meetings

Mr S Savvides, Workshop Superintendent, participated in the annual meeting of the European Higher Engineering and Technical Professionals Association (EURETA) that took place between 3-7 September 1998 in Kopenhagen, Denmark.

Short Courses

The Department of Mechanical Engineering HTI in collaboration with CEA and the Industrial Training Authority organised a short course between 9/11/1998-30/11/1998 on "Statistical Process Control". The course was presented by Dr. I. Angeli, Lab Assistant of the Mechanical Engineering Department.

The Department of Civil Engineering HTI in collaboration with the Industrial Training Authority and the Joint Group of Civil and Mechanical Engineers organised an endorsement Course in "Quantity Surveying Principles and Building Contracts Administration - Part 1 - Tendering and Pricing" between 28/9/99-14/12/1998.

The Department of Civil Engineering HTI in collaboration with the Industrial Training Authority and the Joint Group of Civil and Mechanical Engineers organised an endorsement Course in "Quantity Surveying Principles and Building Contracts Administration - Part 2-Law and Building and Civil Engineering Contracts" between 30/9/1998-21/12/1998.

The Department of Computer Studies HTI in collaboration with the Cyprus Computer Society and the Industrial Training Authority organised the following programmes in "Information Technology":

i) Hands-on Windows NT 4 Server and Workstation" between 2/11/1998-6/11/1998.

ii) "Data Communications and Networks" between 20/10/1998-23/10/1998.

iii) "Hands-on VISUAL BASIC ver. 5.0" between 13/10/1998-16/10/1998.

iv) "Hands-on Windows NT Security" between 23/11/1998-27/11/1998.

v) "Local Area Networks: Implementation and Configuration" between 15/12/1998-18/12/1998.

The Department of Civil Engineering HTI in collaboration with the Industrial Training Authority and the Cyprus Group of Civil and Mechanical Professional Engineers organised a Course Part 3 - Quantity Surveying Principles and Contract Management during January-June 1999.

The Department of Civil Engineering HTI in collaboration with the Industrial Training Authority and the Cyprus Group of Civil and Mechanical Professional Engineers organised a Course "Part 4- Quantity Surveying Principles and Contract Management during February-March 1999.

The Department of Civil Engineering HTI in collaboration with the Industrial Training Authority and the Cyprus Group of Civil and Mechanical Professional Engineers organised a course on "Earthquake Engineering" during February-March 1999.

EUROPEAN PROGRAMME SOCRATES/ERASMUS

Within the framework of the European Programmes SOCRATES/ERASMUS, Mr. M. Poullaides, Senior Lecturer in Civil Engineering Department visited the University of South Bank, London, U.K., between 22-26/3/99.

CONFERENCES / MEETINGS

Dr I. Michaelides, Senior Lecturer in Mechanical Engineering Department, participated in the kick-off meeting for the European Research Project INCO "MED-POL Concerted Action" held in Catania, Italy, between 3-5 March 1999.

Messrs I. Michaelides, Senior Lecturer in Mechanical Engineering Department and S. Kalogirou, Lab Assistant in Mechanical Engineering Department participated in the 4th meeting for the European Research Project INCO "Desalination of Sea-Water using Renewable Energy Sources: held in Jordan, between 24-26 April 1999.

Mr G. Iordanou, Head of the Mechanical-Marine Engineering Department, participated in the short updating course in "Assessment Methodologies and Practices" at the World Maritime University, Malmo, Sweden, between 14-18 April 1999.

Dr. D. Sergides, Senior Lecturer in Civil Engineering Department was invited between March 29 and April 18, 1999 by the "Frank Lloyd Wright School of Architecture" in Taliesin West of Foenic Arizona of U.S.A. and gave a course of lectures on "Bioclimatic Architecture and Energy Conservation".

4. SEMINARS

Dr. D. Sergides, Senior Lecturer in Civil Engineering Department, in co-operation with the Cyprus Architects Association, the Association of Civil Engineers and Architects, the Mechanical engineers association and the International Solar Energy Society of Cyprus, organised and lectured in the training programme for architects and engineers tittled 'Bioclimatic Design of Buildings and Energy Conservation". The course took place at the "Elias Beach Hotel & Country Club", between 15-19 February 1999.

Research of H.T.I.

The Research Programmes listed below are in progress:

(a) Elimination of the vibration problems in switched reluctance Moter Drivers for Electric Cars.

(b) Solar Desalination (EU-INCO).

(c) Background Work for the development of noise models for the road/highway traffic in Cyprus.

(d) Thermochemical processing for the synthesis of nanostructured composite powders and consolidation into net-shaped parts.

(e) Thermal plasma spray robotic deposition of nanostructured material coatings.

(f) Innovative decentralised energy and water management policies (EU-INCO 97).

1998-99 HTI ATHLETIC EVENTS

OCTOBER

Handball Championship for first year students football Champioship for second year students.

Participation of HTI Korfball Team in the European Championship held in Poland.

November

Football Championship for first year students Basketball championship of second year students.

Men's Volley ball received fourth place in Tertiary Education Champioship.

February

Volley-ball champioship for first year students. Indoor football Champioship for second year students.

The Korfball team was invited by the Erasmus University and participated in an International University Championship organised in Rotterdam Holland. Twenty-four University teams from all over the world participated in the above championship and HTI team received ninth place.

March

Volley-ball championship for second year students.

Seven-a-side championship for all students.

The Men's Basket-ball team received third place in the Tertiary Educaton Championship.

The Women's Volley-ball team received third place in the Tertiary Education Championship.

May

The Korfball team received first place in the Tertiary Education Championship second place in the Cup and fifth place in the Tertiary Education Futsal Championship.

The football Team beat the University of Crete team with the score 5-4 (penalty kicks).

During the 1998-99 Cultural Evening, the athletic awards were presented to the HTI successful participants in the various athletic events.

ΚΑΡΤΑ ΥΓΕΙΑΣ ΖΑΚΟ - MEDNET*

* MEDNET: Διεθνής εταιρεία Διαχείρισης Προγραμμάτων Υγείας

Η ΖΑΚΟ ΑΣΦΑΛΙΣΤΙΚΗ με την πολυετή εμπειρία, πριν καταλήξει στην παρουσίαση ενός προγράμματος νοσηλείας ερεύνησε και συνδύασε όλες τις παραμέτρους της υφιστάμενης κατάστασης στο χώρο της υγείας και τις ανάγκες για ασφαλιστική κάλυψη του ανθρώπου του 2000. Το πρόγραμμα περιλαμβάνει μια σειρά από πρωτοποριακές παροχές όπως:

- Άμεση διεθνής κάλυψη στα καλύτερα και μεγαλύτερα Νοσηλευτικά Ιδρύματα του κόσμου.
- Απόλυτη κάλυψη χωρίς περιορισμούς τόσο στην Κύπρο όσο και στο εξωτερικό.
- Εξωνοσοκομειακή κάλυψη, επισκέψεις ιατρών, διαγνωστικές εξετάσεις και φάρμακα.
- Ισχύει για όσο χρόνο επιθυμεί ο πελάτης, ακόμη και εφ όρου ζωής.
- Επιλεκτική κάλυψη ανάμεσα σε 3 κατηγορίες
- Είναι ανεξάρτητη από ασφάλεια ζωής.
- Άμεση βοήθεια επειγόντων περιστατικών.
- Καλύπτονται όλα τα έξοδα τοκετού.
- Κάλυψη των παιδιών από την πρώτη στιγμή της γέννησης τους.
- Χορηγείται χωρίς προηγούμενες ιατρικές εξετάσεις.

Αυτά τα χαρακτηριστικά, σε συνδυασμό με το λογικό κόστος του προγράμματος καθιστούν την κάρτα **ΖΑΚΟ - MEDNET** απαραίτητο και μοναδικό εφόδιο για το σύγχρονο άνθρωπο του 2000.

ΔΕΝ ΧΡΕΙΑΖΕΤΑΙ ΠΛΕΟΝ ΝΑ ΑΠΟΤΑΜΙΕΥΕΤΕ ΧΡΗΜΑΤΑ ΓΙΑ ΤΗΝ ΥΓΕΙΑ ΣΑΣ

ZAKO
ΑΣΦΑΛΙΣΤΙΚΗ

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ON THE AESTHETIC PROBLEM OF SOLAR WATER HEATERS IN CYPRUS

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Ch. Athanasiou, HTI Dipl.

ABSTRACT

The use of thermosyphon solar water heaters for the production of sanitary hot water is a cost effective and widespread application of solar energy in Cyprus. The estimated park of solar collectors in working order is 560,000 m^2, which corresponds to approximately 0.86 m^2 per inhabitant and a contribution to the national energy demand of about 6%. There are however certain problems which are related to the visual and aesthetic point of view. The traditional solar water heater adds a height to the building, which affects the overall appearance and the architecture of the building, and in many cases it is a prohibitive factor for the use of such a unit. This paper elaborates on the problem and proposes improved design configurations of solar water heaters for installation in buildings with flat terrace or inclined roofs.

1. INTRODUCTION

The almost full reliance of Cyprus on imported oil in meeting its energy demand and the abundance of solar radiation together with a good technological base and the popular acceptance of solar energy systems created favorable conditions for the exploitation and utilization of solar energy. Today, the contribution of solar energy to meeting the primary energy needs of the island is estimated to about 6%. Furthermore, it contributes to the reduction in the atmospheric pollution that is estimated to approximately 250,000 tons of CO_2 per year (European Commission, 1996).

Solar energy is almost exclusively used for the production of sanitary hot water, mainly in households. The system mostly used in residential applications is the traditional thermosyphon solar water heater that comprises two flat plate solar collectors of 3 m^2 of surface and a hot water storage tank of 180 litres capacity. The unit is equipped with an auxiliary electric element of 3 kW that boosts the system in case of reduced solar radiation. Owing to the fact that the supply of fresh water to the households in Cyprus is not continuous, a cold water storage tank is necessary, and this is usually located on the top of the solar water heater in order to provide adequate circulating pressure in the distribution circuit. This adds extra height to the unit.

The main problem with the use of this type of solar water heater is its integration to the building it serves and its neighborhood environment, from the construction point of view and the aesthetic. The purpose of this presentation is to propose improved design configurations of solar hot water systems intended for residential applications with flat or inclined roofs, aiming to improve the current situation without affecting the performance of the system.

2. SYSTEM DESIGN

The operation of a thermosyphon solar water heater is based on the thermosyphon principle. The water in the solar collector is heated by the solar energy absorbed by the collector, it expands, and it becomes less dense and rises through the collector into the top of the hot water storage tank. At the same time, colder water, being heavier, is drawn in its place from the bottom of the storage tank. Since the circulating force in the system is only a small density difference, larger than normal plumbing must be used to minimize friction losses in the pipes.

Water flow rate depends on the temperature difference induced as a result of the solar radiation; in bright sun it may be as much as 84 kg/h (Michaelides et al, 1992a). A high flow rate will increase the collector efficiency but will reduce the collector temperature. Another significant factor, which affects the water flow rate, is the vertical distance between the top of the collector and the bottom of the hot water storage tank. The greater this distance is, the larger will be the flow rate. Kreider and Kreith (1977) suggest that the top header of the collector should be at least 30 cm below the cold leg fitting in the storage tank in order to have a satisfactory operation and also avoid reverse water flow during the night. This adds a height to the unit, which is maximized if a vertical cylinder storage tank is used. Furthermore, a cold water storage tank on top of the unit is an additional problem for the households of Cyprus.

Although the thermosyphon solar water heater is a cost-effective application of solar energy in Cyprus (Michaelides et al. 1992b, 1999) and most probably the least expensive type of solar water heater, it does have certain problems. In certain types of buildings for example, it may be undesirable or impossible to place the hot water storage tank above the collector. Generally speaking, the problems are of two kinds:

a) Physical and operational, i.e. how buildings are affected by their surroundings, by each other, overshadowing, etc.

b) Visual or aesthetic problems, i.e. how buildings affect the environment.

Figure 1 shows the layout of a typical installation of solar water heater used in buildings having a flat roof. In addition to the collector and the hot water storage tank, the unit is also equipped with a cold water storage tank, which is placed on top of the unit to build-up adequate pressure in the system. For this purpose, a steel structure is usually used to support the two tanks and the collectors.

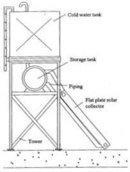

Figure 1. Layout of a typical thermosyphon solar water heater installed on a flat roof

The construction is usually bulky because it has to be strong enough to carry the weight of the two tanks full of water and be able to withstand wind forces acting on the unit. This creates a problem with the aesthetic view of the unit and the building architecture, owing to the increased height of the unit, which is usually extended on the roof of the house. This is a drawback for the system because it affects the overall appearance of the building itself.

In cases where the building has inclined roofs, it is rather difficult to use the unit shown in fig. 1. In such a case, a different configuration is used as illustrated in fig. 2. The solar collectors are placed above the tiles, on a roof that faces south or nearly south. If the inclination angle of the roof deviates from the optimum collector tilt angle, which is around 35 degrees from horizontal (Michaelides 1997), then a special steel structure is needed to provide for the necessary correction. If the roof inclination is within (10 degrees from the optimum collector tilt angle, the collector is placed on the roof, above the tiles. The hot water storage tank is also mounted on the tilted roof, just above the top header of the collector, in order to take advantage of the thermosyphonic effect and avoid the use of a pump. This arrangement is not as ugly as the previous configuration, but there is a problem with the installation of the cold water storage tank. This is usually resolved by the use of a pressurized water system in the building.

Incases where the above arrangement is not feasible for practical or other reasons, a small part of the south facing roof can be replaced by a flat terrace to accommodate the solar water heater unit, including the cold water tank. Such an arrangement will improve the situation but will incur additional building costs.

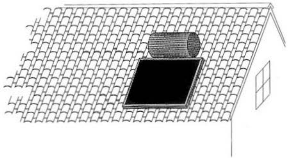

Figure. 2. Typical installation of solar water heater on inclined roofs

3. IMPROVED DESIGN CONFIGURATIONS

There are several ways by which the visual or aesthetic problem can be alleviated without affecting the system performance, such as the following (Szokolay, 1975):

a) Collectors with integral horizontal tanks should be used in preference to vertical cylinders.
b) Units should be located in a line along the centre of the roof, to avoid visibility from below.
c) They may be located near the northern edge of the roof, if provision is made for cover by a parapet and if view from above is likely.
d) Integration with the building, i.e. the use of collectors as building elements; they may become part of the roof, a balcony balustrade, a canopy over a window or any other form of shading device.

The need of improving the design configurations rises straight from the definition of the problem. However, improving the design must not decrease the overall efficiency of the system and should maintain the appearance of the installation as much more pleasing as possible. Following are some proposals, which offer solutions to the problem without considerable increase in the cost.

Fig. 3 illustrates three different ways of arranging two flat plate solar collectors, which usually make part of a thermosyphon solar water heater. Generally, for a house of 4 persons, two flat plate solar collectors are adequate.

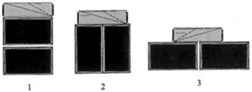

Figure 3. Possible arrangement of solar collectors in a solar water heater

As it is seen in fig. 3, the third arrangement where the collectors are placed side by side, with their longer side horizontal, has the lowest profile. Therefore the overall height of the construction is reduced. This is a useful tip for systems that are to be mounted on flat roofs. In arrangement 1, the two collectors are placed with the long side parallel in horizontal position. This is recommended for cases where the long side is more than twice the width of the collector. In the latter case the collectors are placed with the short side parallel to the horizontal, the one next to the other. If there is no restriction in the space available on the roof then the solution 3 is recommended for minimum height and therefore better appearance.

Fig. 4 illustrates a design configuration intended for inclined roofs. The solar collector is mounted directly on the surface of the inclined roof, replacing the tiles. This arrangement provides for a harmonic integration of the solar system into the building structure. The cold and hot water storage tanks can be placed into the attic space as shown in fig. 4, in a way that thermosyphonic effect is facilitated. If the height of the attic space is not enough to accommodate the hot water storage tank and provide for thermosyphon circulation, the storage tank will have to be place at a lower level and a pump should be used for the water circulation. The circulating pump could be powered by a photovoltaic cell as shown in fig. 6.

In case that the inclination of the roof deviates from the optimum collector tilt angle, the collector arrangement illustrated in fig. 5 can be used. The collector is placed on the roof at the desired tilt angle and is then integrated in special construction (housing) decorated with tiles so that the overall construction is aesthetically pleasant.

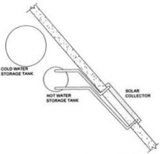

Figure 4. Solar water heater with storage tanks hidden in the roof attic

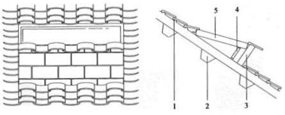

Figure 5. Arrangement of collector on inclined roof for optimum collector tilt angle (1 tiles, 2 inclined roof, 3 plasterboard, 4 bracket, 5 solar collector)

Another way to reduce the height of the solar water heater is to use a pump for the circulation of water in the system. This will allow the placement of the hot water storage tank at a level lower than the collector upper header. A design configuration based on this principle of operation is shown in fig. 6. This layout is intended for flat terrace roof applications. The circulating pump 6 is powered by a photovoltaic cell (4) and operates only during sunshine hours. The collectors are placed with their long side horizontally, as shown in fig. 3 (3), providing a lower profile. The hot water storage tank (6) is placed behind the collectors at low level.

If desirable, the unit can be accommodated into a special housing, so that only the collector front surface is visible, as shown in fig. 7. For a more compact construction, the collectors are arranged one on top of the other as shown in the figure.

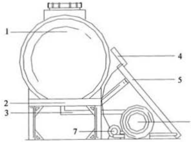

Figure 6. Active solar water heater powered by a photovoltaic cell (1 cold water storage tank, 2 support tower, 3 piping, 4 photovoltaic cell, 5 solar collector, 6 hot water storage tank, 7 pump)

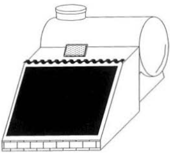

Figure 7. Housing layout of a compact active solar water heater

CONCLUSIONS

The typical solar water heater in Cyprus, operating on the thermosyphon principle, is usually provided with a cold water storage tank, which is placed above the hot water storage tank. This increases the height of the unit and creates visual or aesthetic problems for the building it serves and its surrounding environment. A number of methods and design configurations have been proposed aiming to improve the situation without affecting the performance of the unit. These include configurations suitable for flat terrace roofs as well as inclined roofs.

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Method for producing amorphous based metals

N. Angastiniotis, Mechanical Engineering Department

While Dr. Nicos Angastiniotis was affiliated with the Laboratory for Nanostructured Materials at Rutgers University USA, he collaborated also with the Research and Development group at Nanodyne Incorporated on a wide range of projects and initiatives at the cutting edge in the synthesis and processing of nanostructured materials. This collaboration resulted in pioneering research and spearheaded, among various other breakthroughs and the development of a proprietary method for producing amorphous based metals. This method has been patented and registered in the U.S. Patent and Trademark Office (USPTO), the European Patent Office (EPO), the Japanese Patent Office (JPO) and the Canadian Intellectual Property Office (CIPO).

The patent in reference is cited on the internet and can be accessed on the USPTO web-site (patent number US5776264), the EPO web-site (patent number EP0800883), the JPO web-site (publication number JP9309704) and CIPO web-site (patent document number CA2190422).

The following is a reprint.

US PATENT & TRADEMARK OFFICE

United States Patent **5,776,264**

McCandlish, Kear, Angastiniotis **July 7, 1998**

Method for producing amorphous based metals

Abstract

Amorphous tungsten, cobalt, nickel, molybdenum, iron and alloys thereof can be formed by reducing metal-containing compositions to form the elemental metal wherein the particle size of the elemental metal is less than about 80 microns. This is oxidized in an oxygen-starved environment containing less than 3% oxygen and an inert gas to slowly oxidize the elemental metal. By oxidizing the metal under these conditions, the normal exotherm occurring during oxidation is avoided. The slow oxidation of the metal continues forming an amorphous metal oxide. The amorphous metal oxide can then be reacted in a reducing environment such as hydrogen to form the amorphous elemental metal. This amorphous elemental metal can then be reacted with a carburizing gas to form the carbide or ammonia gas to form the nitride or hexamethylsilane to form the silicide. This permits gas/solid reactions. The amorphous metal can also be used in a variety of different applications.

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Appl. No.: **631453**

Other References

Formation and Alloying of Nanostructured β-W Powders, N.C. Angastiniotis, B. H. Kear, L.E. McCandlish, K.V. Ramanujachary, M. Greenblatt, Nanostruct. Mat., 1,293 (1992).

Chemical Processing and Properties of Nanostructured W-Base Materials, B.H. Kear, L.E. McCandlish, SAMPE Quarterly, (1993).

Primary Examiner: Wyszomierski; George

Attorney, Agent or Firm: Wood, Herron & Evans, L.L.P.

Goverment Interests

GOVERNMENT INTEREST

Work leading to this invention was funded in part through ONR Control #N00014-91-J-1818. Accordingly, the United States government may own certain rights in this invention.

Claims

1. A method of forming an amorphous metal compound of a metal selected from the group consisting of tungsten, molybdenum, tungsten-molybdenum alloys, alloys containing tungsten or molybdenum and a metal selected from the group consisting of chromium, iron, cobalt and nickel comprising;

reducing a composition containing said metal to form metal; and

oxidizing said metal at a temperature less than about 350.degree. C. in an environment comprising less than about 3% oxygen in an inert gas, thereby oxidizing said elemental metal without generating an exotherm, and forming amorphous metal oxide.

2. The method claimed in claim 1 further comprising reducing said amorphous metal oxide to form amorphous metal.

3. The method claimed in claim 2 wherein said composition containing said metal is a solid compound having a particle size of less than 80 microns.

4. The method claimed in claim 2 wherein said metal is tungsten.

5. The method claimed in claim 2 wherein said metal comprises a mixture of tungsten and molybdenum.

6. A method of forming amorphous metal, said metal selected from the group consisting of tungsten, cobalt, nickel, molybdenum, iron and mixtures thereof comprising;

oxidizing elemental metal in an environment comprising less than about 3% oxygen in an inert gas at a temperature of less than 350.degree. C. wherein said elemental metal has a particle size of less than 80 microns thereby oxidizing said elemental metal without generating an exotherm and forming amorphous metal oxide; and

reducing said amorphous metal oxide to form amorphous elemental metal.

7. A method of forming amorphous metal nitride of a metal selected from the group consisting of tungsten and molybdenum comprising reducing a composition containing said metal to form elemental metal;

reacting said elemental metal in an environment comprising less than about 3% ammonia in an inert gas at a temperature less than 350.degree. C., thereby forming amorphous metal nitride without generating an exotherm.

8. A method of forming an amorphous metal carbide compound of a metal selected from the group consisting of tungsten and molybdenum comprising reducing a composition containing said metal to form elemental metal;

carburizing said elemental metal in an environment comprising less than about 3% carburizing gas in an inert gas at a temperature less than 350.degree. C., thereby forming amorphous metal carbide without generating an exotherm.

Description

BACKGROUND OF THE INVENTION

The present invention relates to the formation of amorphous metal powders and, in addition, relates to a method of producing amorphous tungsten, molybdenum and molybdenum alloys and their alloys with chromium, iron, cobalt and nickel and, further, to the use of these powders to form refractory metal compounds of nanocrystalline grain size.

Elemental metals, as well as compounds formed from metals, exist in a variety of different crystalline states. These elements and compositions can exist in a totally crystalline state which, of course, can take on several different forms, and further the crystalline form can often be varied. These different crystalline forms, as well as the degree of crystallinity of metal-containing compositions, effect the reactivity of the composition.

Generally, metal-containing compositions can be reduced to form the elemental metal by heating the composition in the presence of a reducing environment such as hydrogen. The formed elemental metal will generally be crystalline. The elemental metal can also be reoxidized. The oxidation is generally exothermic. Under elevated temperatures in the presence of oxygen, the oxidation reaction is spontaneous. Again, the formed oxide will be, in general, crystalline. This oxidation/reduction can be repeated and the crystallinity remains the same under the same condition.

Low surface area can significantly interfere with reactivity of a powder. Crystalline powders comprising large crystalline grains have low surface area hiding interior atoms from reactive chemicals. High surface area nanocrystalline metal powders, on the other hand, are very reactive. They often oxidize at room temperature on contact with air.

Numerous studies of oxidation/reduction have been conducted on many different metals. Tungsten and molybdenum, in particular, has been studied extensively.

For several decades numerous attempts have been made to produce tungsten powder by reduction using sodium, magnesium, calcium, aluminum, silicon and zinc. For example, Oage has successfully reduced tungsten trioxide (WO.sub.3) with zinc and hydrogen at about 800.degree. C. After synthesis, the zinc oxide is leached out with hydrochloric acid.

Today on an industrial scale, tungsten powder is prepared by hydrogen reduction of tungsten trioxide. Final particle size is determined by controlling the reduction temperature and moisture content of the reducing gas. The yellow oxide powder is loaded in boats and the reduction carried out in push furnaces using a high rate of hydrogen flow to remove the water. Numerous publications exist that describe the mechanism of reduction of tungsten trioxide in hydrogen in the formation of other tungsten oxygen compounds. The most definitive studies on reduction of tungsten oxides to metals have been performed by Haubner, et al.

SUMMARY OF THE INVENTION

The present invention is premised on the realization that amorphous metals can be formed from metal oxides by reducing the metal compound in a hydrogen atmosphere at elevated temperature. Slow, low-temperature, controlled reoxidation of the metal compound promotes a decrease in oxide grain size, i.e., if the reoxidation is properly controlled so that the exotherm from the oxidation reaction is prevented. This works with easily-oxidized metals such as tungsten and molybdenum. This works with both the alpha tungsten and beta tungsten forms.

Further, these amorphous metals and alloys of these metals can then be reacted with gas compositions at low temperature to form refractory metal compounds such as nitrides, carbides and silicides. The objects and advantages of the present invention will be further appreciated in light of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the x-ray diffraction patterns of the products of the sequential reactions described in Example 2.

FIG. 2 shows the x-ray diffraction patterns of the products of the reactions described in Example 3.

FIG. 3 shows the x-ray diffraction patterns of the products of the reactions described in Example 4.

DETAILED DESCRIPTION

The present invention is a method of forming amorphous metals, specifically tungsten and molybdenum and their alloys with chromium, iron, cobalt, and nickel. The starting materials useful for formation of these amorphous metals can be any chemical composition that includes these metals, although oxides and oxygen-containing salts are preferred.

Specific tungsten compositions include elemental tungsten, tungsten oxides and ammonia metatungstate. Basically, any tungsten compound which does not contain atoms which can be driven off such as other unwanted metals can be used. Compositions which contain only tungsten and oxygen, nitrogen, carbon or hydrogen are quite suitable. If an alloy is desired, a mixture of the tungsten compound and a similar composite formed from a second metal serve as the starting material.

Specific molybdenum compositions include elemental molybdenum, molybdenum oxides and ammonium molybdate, which is water soluble.

Preferably, the particle size of the starting material will be from about 80 to about 5 microns in size or less. The particle size can be established by, for example, grinding the composition or more easily can be formed by forming a solution of the chemical composition and spray drying this. This method permits not only single composition particles to be formed, but also particles formed from two or more compositions so that ultimately an amorphous alloy is formed.

The solution can be of any dilution up to saturation of the individual components. The solvent can be water or an organic solvent. The particular solvent or chemical composition is not particularly important, although water is preferred for environmental reasons. The solution itself should be formed with the starting materials in a ratio equal to the desired ratio of the metals of the desired end product. Thus, if an alloy having equal amounts of iron and cobalt is desired, the starting solution should have equal amounts of tungsten and molybdenum.

As described, these are preferably spray dried to form amorphous particles having a particle size of about 80 to about 5 microns.

The particles are then reduced in a hydrogen environment at a temperature below the melting point of the composition. This can vary from about 500.degree. C. up to about 1,000.degree. C.

The reduction is conducted in a reducing environment and preferably is conducted in a hydrogen-containing atmosphere. This is continued until substantially complete reduction occurs. This will form the metal composition.

In order to form the amorphous metal composition, the reduced metal particles are then subjected to a controlled reoxidation. With each of these metals, the uncontrolled oxidation will produce an exotherm, creating a rapid reaction, driving all the composition to the oxide form almost instantaneously. However, by controlling the oxidizing environment, the exotherm can be avoided. This is controlled by maintaining the temperature at about 300.degree. C. to 350.degree. C. and controlling the oxygen content of the environment at about 0.5% to about 3% oxygen, preferably 1% to 2%, with the remainder of the environment being an inert gas such as argon or nitrogen.

Over a period of about several hours, the reaction will go to completion, forming the oxide. The oxide is amorphous in form, which means when subjected to X-ray crystallography it fails to produce any characteristic crystalline peak. The elemental amorphous metal can then be formed by reducing the amorphous oxide at elevated temperature in a hydrogen atmosphere. This will, in turn, form elemental amorphous metal or metal alloys which will generally have a particle size varying from about 50 nanometers down to less than or equal to 100 angstroms in size. If the metal is not completely amorphous, the oxidation and reduction can be repeated and the crystallinity will be reduced or eliminated.

The initial reduction of tungsten can form the .beta.-tungsten species. The .beta.-tungsten can also be reacted with ammonia (instead of oxygen) to form amorphous tungsten nitride. The .beta.-tungsten can also be reacted with carbon monoxide to form amorphous tungsten oxycarbide. Again, with these reactions it is important to control the temperature and concentration of reactant gas (NH.sub.3 or CO) to avoid a rapid or strong exothermic reaction. As with the oxidation reaction, the nitridation or carburization reaction must be conducted at less than about 350.degree. C.

As previously indicated, this reaction can be conducted with tungsten, molybdenum, alloys of tungsten and molybdenum, as well as iron, chromium, cobalt and nickel alloys of tungsten or molybdenum.

Once formed, the elemental amorphous metal can be further reacted to form refractory metal compositions. The individual metal composition or alloys can be reacted in the presence of ammonia to form the nitride composition. The elemental amorphous metal can also be reacted with a carburizing gas, such as a carbon dioxide-carbon monoxide mixture, to form the metal carbide. These can also be reacted with hexamethyldisilazane to form the silicide.

The carburization reaction to form the carbide of the individual compositions can be conducted in a fixed bed or fluidized bed reactor in a controlled environment with a carburizing gas such as carbon monoxide, carbon dioxide, methane or ethane. Generally, the reaction mixture will have sufficient carburizing gas in an inert environment to establish a carbon activity of about 1. This is passed through the amorphous metal.

The reaction is conducted at a temperature of about 550.degree. C. to about 700.degree. C. over a period of 20 to 240 minutes. The formed carbide should have a particle size of less than 20 nanometers, preferably less than 10 nanometers.

The present invention will be further appreciated in light of the following detailed examples.

EXAMPLE 1

Preparation of amorphous tungsten via .alpha.-tungsten

Ammonium metatungstate (AMT) was pyrolyzed by heating in flowing helium to 500.degree. C. to product WO.sub.3-x, a mixture of WO.sub.3 and WO.sub.2.9. The WO.sub.3-x was reduced in hydrogen at 625.degree. C., reoxidized in a 2% mixture of oxygen in helium, and finally re-reduced in hydrogen to produce high surface area .alpha.-tungsten, .alpha.-W. The high surface area .alpha.-W was cooled to 25.degree. C. in flowing helium gas and then heated in a series of steps to 300.degree. C. in flowing 2% O.sub.2 /He to produce amorphouse tungsten oxide, .gamma.-WO.sub.x.

Temperature (.degree.C.)	Time (minutes)
25	300
100	200
200	200
250	600
300	1800

The .gamma.-WO.sub.x was heated in flowing hydrogen to 400.degree. C. upon which it reduced to amorphous tungsten, .gamma.-W.

EXAMPLE 2

Preparation of amorphous tungsten via .beta.-tungsten

Ammonium metatungstate (AMT) was pyrolyzed by heating in flowing helium to 500.degree. C. to produce WO.sub.3-x, a mixture of WO.sub.3 and WO.sub.2.9. The WO.sub.3-x was reduced in hydrogen at 500.degree. C., reoxided in a 2% mixture of oxygen in helium, and finally re-reduced in hydrogen to produce high surface area .beta.-tungsten, .beta.-W. The high surface area .beta.-W was cooled to 25.degree. C. in flowing helium gas and then heated in a series of steps to 300.degree. C. in flowing 2% O.sub.2 /He to produce amorphous tungsten oxide, .gamma.-WO.sub.x.

Temperature (.degree.C.)	Time (minutes)
25	90
100	200
200	200
250	200
300	170

The .gamma.-WO.sub.x was heated in flowing hydrogen to 400.degree. C. upon which it reduced to amorphous tungsten, .gamma.-W. This is further depicted in FIG. 1.

EXAMPLE 3

Preparation of amorphous tungsten nitride via .beta.-tungsten

.beta.-W is heated in a series of steps to 300.degree. C. in flowing ammonia gas to produce amorphous tungsten nitride, .gamma.-WN.sub.x or .delta.-WN.sub.x.

Temperature (.degree.C.)	Time (minutes)
.gamma.-WN.sub.x	
25	90
100	300
200-300	400
.delta.-WN.sub.x	
25	90
100-300	400

This is further depicted in FIG. 2.

EXAMPLE 4

Preparation of amorphous tungsten oxycarbide via .beta.-tungsten

.beta.-W is heated in a series of steps to 300.degree. C. in flowing ammonia gas to produce amorphous tungsten nitride, .delta. WC.sub.x O.sub.y.

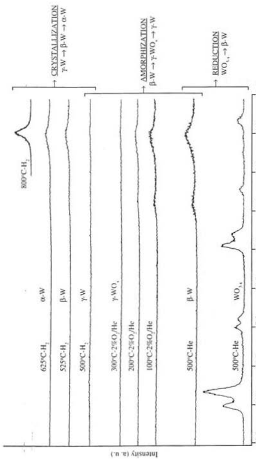
Temperature (.degree.C.)	Time (minutes)
25	100
100	200
200-300	400

This is further depicted in FIG. 3.

In addition to being useful for formation of silicides, carbides and nitrides and other refractory composition, the present invention is also useful in the elemental form to provide amorphous powder coatings and the like. They can also be blended with compositions for alloying and used in any application in which elemental metal is employed. The amorphous metal oxide can also be used in any reaction calling for such an oxide. The decreased particle size should facilitate mixing and improve reactivity. The particle size of the oxides makes these oxides useful as pigments and coatings and in ceramics.

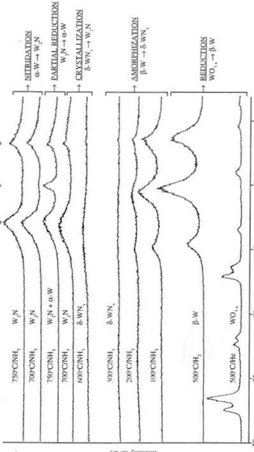
The preceding has been a description of the present invention in such terms that will allow those skilled in the art to practice this invention. Further, the best mode of practicing this invention is also disclosed herein. wherein we claim:

* * * * *



CRYSTALLIZATION
γ-W → β-W → α-W
AMORPHIZATION
β-W → γ-WO3 → γ-W
REDUCTION
WO3-x → β-W
800°C-H2
625°C-H2
α-W
525°C-H2
β-W
500°C-H2
γ-W
300°C-2%O2/He
γ-WO3
200°C-2%O2/He
100°C-2%O2/He
500°C-He
β-W
500°C-He
WO3-x
Intensity (a. u.)
°2θ
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
40.0
42.5

Fig. 1



W_2N
α-W
W_2N
NITRIDATION
α-W → W_2N
PARTIAL REDUCTION
W_2N → α-W
CRYSTALLIZATION
δ-WN_x → W_2N
AMORPHIZATION
β-W → δ-WN_x
REDUCTION
WO_{3-x} → β-W
750°C/NH_3 W_2N
700°C/NH_3 W_2N
750°C/NH_3 W_2N + α-W
700°C/NH_3 W_2N
600°C/NH_3 δ-WN_x
300°C/NH_3 δ-WN_x
200°C/NH_3
100°C/NH_3
500°C/H_2 β-W
500°C/He WO_{3-x}
Intensity (a. u.)
20
25
30
35
40
45
°2θ

Fig. 2

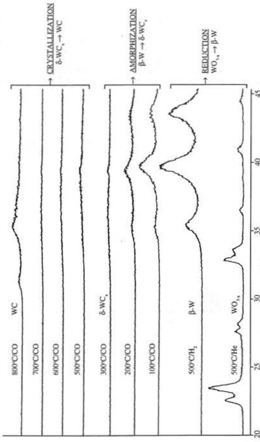

CRYSTALLIZATION
δ-WCx → WC
AMORPHIZATION
β-W → δ-WCx
REDUCTION
WO3-x → β-W
800°C/CO
700°C/CO
600°C/CO
500°C/CO
300°C/CO
200°C/CO
100°C/CO
500°C/H2
500°C/He
WC
δ-WCx
β-W
WO3-x
Intensity (a. u.)
°2θ
20
25
30
35
40
45

Fig. 3

Nanomaterials Research Center

N. Angastiniotis, A. Stassis, Mechanical Engineering Department

Nanostructured materials are both scientifically interesting and technologically important. Superior properties have been demonstrated for a broad range of such materials. Examples include materials whose strengths approach theoretical limits, ceramics and intermetallics that possess ductility, and materials with enhanced magnetic, electronic and optical properties. These property improvements derive from structural features, such as grain size or layer thickness on a scale 1-100 *nm*, much smaller than that found in conventional materials. Potential applications for nanostructured materials include paint pigments, cosmetics, pharmaceuticals, medical diagnostics, catalysts and supports, membranes and filters, batteries and fuel cells, electronic, magnetic and optical devices, flat panel displays, biomaterials, structural materials, and protective coatings.

The primary mission of the Nanomaterials Research Center (NRC) is to develop new methods for the economical production of nanonstructured (n-) metals, ceramics, and their composites. A feature of the Center research is that it encompasses all elements of the Materials Science and Engineering continuum, including synthesis, processing, composition, structure, properties, performance, diagnostics and modeling. Examples of recent research with potential impact in the industrial arena are (1) synthesis of n-metal, n-ceramic, and n-cermet powders from aqueous solution and vapor phase precursors, (2) densification of n-ceramic powders by pressure-less sintering and hot pressing at exceptionally low temperatures, and (3) demonstration of superior properties for optical, magnetic, electrical, chemical and structural applications.

Current research is focused on methods for the production of high surface area nanopowders (catalysts, dielectrics, transducers, optical amplifiers), nanophase coatings (wear resistant surfaces, thermal barriers, solar sell fabrications, photovoltaic systems), and nanophase composites (gas turbine engines, bulletproof vests). For nanophase diamond and cubic BN, a *detonation* method appears to be particularly promising. Methods are also being developed for consolidating n-ceramic powders, without inducing significant grain coarsening. To develop engineering approaches for these new technologies, and to assist our industrial partners in their scale-up for industrial use, we are examining the gas and liquid phase synthesis environments using various non-intrusive diagnostic probes, e.g. X-ray diffraction methods, thermogravimetric analysis and validated computer modeling. Thus, an important outcome of our research will be procedures for *in situ* monitoring and *closed-loop* control over the actual production processes.

In order to further promote technology transfer, the Nanomaterials Research Center serves as a bridge for technology development between the science/technology creators (the HTI faculty and students) and the technology users (industry at large). Under this center, an array of operating divisions is being established, each with its own application goal(s) and commercialization strategy. Now in its first year of operation, NRC has already established two operating divisions: (1) nanopowder synthesis, which is commercializing high rate production of non-agglomerated nanoparticles and (2) large area deposition of coatings. Both of the divisions are to focus on the commercialization of advanced materials processes for enhanced mechanical properties.

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Best Projects in Plant and Production Engineering

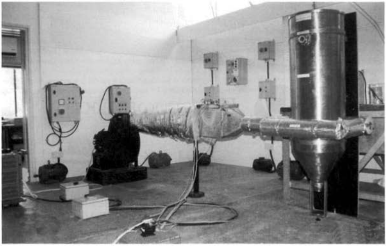
N. Angastiniotis, Mechanical Engineering Department

With a view to promoting technology transfer, Dr. Nicos Angastiniotis has been spearheading an initiative by which the Higher Technical Institute will serve as a bridge for technology development between the science/technology creators (the Higher Technical Institute faculty and students) and the technology users (industry at large). Under this endeavor, a state-of-the-art Nanomaterials Research Center (NRC) is being established at the Higher Technical Institute, aiming at its own application goal(s) and commercialization strategy. Now in its first year of operation, NRC has already established two operating divisions: (1) nanopowder synthesis, which is focusing on commercialization high rate production of non-agglomerated nanoparticles and (2) large area deposition of super-hard materials.

Within the framework of the nanopowder synthesis division, four final year projects were proposed by Dr. Angastiniotis and subsequently assigned to graduating Mechanical Engineering students. Three of these projects were awarded the prize for the best projects in the Mechanical Engineering Department. Specifically, the project under the title, "Design and Construction of an Atmosphere-Controlled Incubator" which was assigned to Georgios Ioannides was awarded the prize for the "Best Project in Production Engineering" whereas the projects under the titles, "Design of a Droplet Generator (Liquid Atomizer)" assigned to Georgios Tziortzis and "Design of an Adiabatic Drying Mechanism for Liquid Droplets" assigned to Michael Zambas shared the prize for the "Best project in Plant Engineering".

A feature of all aforementioned three projects is that it encompasses all elements of the Materials Science and Mechanical Engineering continuum, including thermodynamics, fluid mechanics, synthesis, processing, composition, structure, properties, performance, diagnostics and modeling.

It must be stated emphatically that even though the particular assignment for each project was unique and distinctly different, the students worked closely with each other and eventually were very proud to devise their own apparatus as this is depicted below:



Most importantly, the students during the course of their effort had the opportunity to collaborate closely with several Cypriot companies such as Larticon Synthetic Detergents Co., Deksa Central Heating Equipment, the Oxygen-Acetylene Industries Ltd, Anaxagoras Pneumatics Ltd, Christakis Agathangelou Manufacturers Ltd, Arhimedes Ltd, Sprel Electronic Services, Caledonian Commercial Co. Ltd and nine other medium size companies. Valuable input was also provided by the Electrical Engineering Department of HTI and more specifically by the lecturer Mr. Ioannis Demetriou, the senior instructor Mr. Costas Georgiades, the instructors Mr. Panicos Hadjimichael and Mr. Soteris Avgousti as well as by the workshop Superintendent Mr. Savvas Savvides.

In conclusion, the evaluation regarding the experimental results was conducted by the State Chemical Laboratory, the Geological Survey Department and the Cyprus Institute of Neurology and Genetics.

MODELLING OF THE MODERN HOUSES OF CYPRUS AND ENERGY CONSUMPTION ANALYSIS

G. A. FLORIDES, Mphil, Senior Instructor, HTI

S. A. KALOGIROU, Mphil, PhD, Eur Ing, CEng, MCIBSE, MASHRAE, Instructor, HTI.

ABSTRACT

This study uses TRNSYS to model and simulate the energy flows of the modern houses of Cyprus, followed by an energy consumption analysis. For the calculations, a Typical Meteorological Year for the Nicosia area and a typical model house are used. The inside house temperature, when no air-conditioning is used, is estimated. This temperature varies between 10-20°C for winter and between 30-45°C for summer. The effect on the temperature and the heating and cooling loads that various wall and roof constructions have, is determined. This investigation indicates the importance of the roof insulation, which results in a reduction up to 47% of the cooling load and up to 73% of the heating load. Also the effect of mechanical ventilation, as well as that of the inclined concrete roof, used for aesthetic reasons, is examined. The life cycle cost analysis is used for the economic analysis of the various constructions. The results indicate that the wall insulation nearly pays back in a twenty years period, with marginal negative savings, whereas the roof insulation has considerable economic benefit with a life cycle savings of C£6770 up to C£8680 depending on the room temperature and the insulation thickness.

1. INTRODUCTION

In designing for cooling, adequate results are obtained when using heat losses based on steady-state heat transfer. This is the everyday practice of building services consulting offices. But since the heat gain into a conditioned space is quite variable with time, primarily because of the strong transient effects created by the hourly variation in solar radiation, transient analysis must be used. The difference caused by the storage or transfer of energy from the structure and contents to the circulated air must be taken into account otherwise the cooling and dehumidifying equipment will usually be oversized.

It is important to refer to three basic terms, which will be used extensively in this paper, namely:

(a) Heat Gain

Heat gain is the rate at which energy is transferred to or generated within a space and consists of sensible and latent gain. Heat gains usually occur in the following forms:

- Solar radiation through openings
- Heat conduction with convection and radiation from the inner surfaces into the space
- Sensible heat convection and radiation from internal objects
- Ventilation and infiltration
- Latent heat gains generated within the space.

(b) Cooling Load

The cooling load is the rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. The cooling load differs from the heat gain mainly because the radiant energy from the inside surfaces as well as the direct solar radiation passing into a space through openings, is mostly absorbed in the space. This energy becomes part of the cooling load only when the room air receives the energy by convection and occurs when the various surfaces in the room attain higher temperatures than the room air. This time lag depends on the storage characteristics of the structure and interior objects and is more significant when the thermal mass (product of mass and specific heat) is greater. This means that the reduction in the peak cooling load can be quite important in sizing the cooling equipment. The sensible heat component from people, the lights and equipment acts in a similar way. This means that about the same total amount of energy must be removed from the structure during the day but a larger portion must be removed during the evening hours especially for heavier constructions.

(c) Heat Extraction Rate

The heat extraction rate is the rate at which energy is removed from the space by the cooling and dehumidifying equipment. This rate is equal to the cooling load when the space conditions are constant and the equipment is operating. Since the operation of the control systems needs some fluctuation in the room temperature and also the cooling load is also below the peak design value, intermittent or variable operation of the cooling equipment is required.

There are many methods that can be used to estimate the cooling load. One of these methods is the transfer function approach, which simplifies the calculations, can provide the loads originating from various parts of the building and can be used to determine the cooling loads.

2. THE TRANSFER FUNCTION METHOD

The ASHRAE Task Group on Energy Requirements developed the general procedure referred to as the Transfer Function Method (TFM). The method is based on series of conduction transfer functions (CTF) and room transfer functions (RTF). These functions are response time series, which relate a current variable to past values of itself and other variables in one-hour periods for building analysis.

Omar and Khalid (1997) have used the transfer function method to predict the hourly cooling load due to different types of wall, roof and fenestration. The outputs of the program developed by the authors based on the transfer function method was tested with a commercially available program and the agreement was satisfactory.

2.1 Wall and Roof Transfer Functions

$$\dot{q}_{e,\theta} = A\left[\sum_{n=0} b_n\left(t_{e,\theta-n\delta}\right) - t_{rc}\sum_{n=0} c_n - \sum_{n=1} d_n\left(\dot{q}_{e,\theta-n\delta}/A\right)\right] \tag{1}$$

where:

- $\dot{q}_{e,\theta}$ = heat gain through wall or roof, at calculation hour Θ
- A = indoor surface area of wall or roof
- θ = time
- δ = time interval
- n = summation index (each summation has as many terms as there are non-negligible values of coefficients)
- $t_{e,\theta-n\delta}$ = sol-air temperature at time Θ-nδ
- t_{rc} = constant indoor room temperature
- b_n, c_n, d_n = conduction transfer function coefficients

Conduction transfer function coefficients depend only on the physical properties of the wall or roof. These coefficients are given in tables (ASHRAE Fundamentals Handbook, 1997). The *b* and *c* coefficients must be adjusted for the actual heat transfer coefficient (U_{actual}) by multiplying with the ratio $U_{actual}/U_{from\ wall\ type}$.

In equation (1) a value of the summation index *n*, equal to zero represents the current time interval, n equal to one is the previous hour and so on.

The sol-air temperature is defined as:

$$t_e = t_o + \alpha\, I_t/h_o - \varepsilon\, \delta R/h_o \tag{2}$$

where:

te = sol-air temperature (°C)

t_o = current hour dry-bulb temperature (°C)

α = absorptance of surface for solar radiation

I_t = total incident solar load (W/m²)

δ = time interval (hours)

$\varepsilon\ \delta\ R\ /\ h_o$ = long-wave radiation factor = -3.9°C for horizontal surfaces, 0°C for vertical surfaces.

The term α/h_o in equation (2) varies from about 0.026 m^2 K / W for a light-coloured surface to a maximum of about 0.053 m^2 K / W.

2.2 Partitions, Ceilings and Floors

Whenever a conditioned space is adjacent to other spaces at different temperatures, the transfer of heat through the partition can be calculated by equation (1), by replacing the sol-air temperature with the temperature of the adjacent space.

2.3 TRNSYS Overview

TRNSYS is a transient systems simulation program with a modular structure and is used in the present study for deriving the results. The modular nature of TRNSYS makes the program flexible, and facilitates the addition of extra mathematical models to the program. TRNSYS is well suited to detailed analyses of systems whose behaviour is dependent on the passage of time and is designed to simulate the transient performance of thermal energy systems. The program can solve large systems of equations described by Fortran subroutines. Each Fortran subroutine contains a model for a system component. By creating an input file, usually called deck file, the user directs TRNSYS to connect the various subroutines to form a system. The TRNSYS engine calls the system components based on the input file and iterates at each time-step until the system of equations is solved. The flow chart of the deck file, written as part of this project is shown in Figure 1.

TRNSYS allows the users to completely describe and monitor all interactions between system components. The program library includes many of the components commonly found in thermal energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modularity of the program allows the user to have as many pumps, chillers, cooling coils and solar panels as necessary, in any desired configuration. For the present study, Type 19 TRNSYS model will be used (TRNSYS, 1998) to estimate the heating and cooling loads for a model building. All heating and cooling loads arising from walls, windows, flat roofs and floors are calculated with Type 19 model, by utilizing the transfer function method.

This model has two basic modes of operation, i.e., the energy rate and the temperature level control modes. In the study, the temperature level control mode is selected, since with this mode the temperature of the building can be maintained between specified limits and the energy required to maintain the zone in the specified temperature is given as output along with the limit temperature. The zone humidity ratio is also allowed to float between a maximum and a minimum limit specified by the user and the humidification or dehumidification energy is considered. Additionally, heat may be added or removed by the use of a ventilation flow stream or an instantaneous heat gain input and a controller is used in conjunction with this mode to control the heating or cooling equipment.

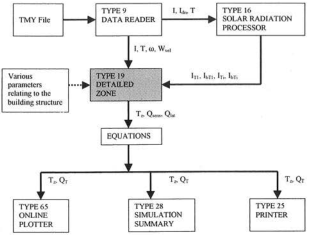


Figure 1. Flow chart of the TRNSYS deck file.

Note: the symbols represent:

- I - global solar radiation on a horizontal surface at the next hour (kJ/h)
- I_{dn} - direct normal solar radiation at the next hour (kJ/h)
- T- dry-bulb temperature at the next time step (°C)
- ω- humidity ratio at the next time step
- W_{vel} - wind velocity at the next time step (m/s)
- I_{T1}, I_{Ti} - total radiation on surface number 1or i (kJ/m^{2}h)
- I_{bT1}, I_{bTi} - beam radiation on surface number 1or i (kJ/m^{2}h)
- T_z- zone temperature (°C)
- Q_{sens} - sensible load (kJ/h)
- Q_{lat} - latent load (kJ/h)
- Q_T - total load (kJ/h)

Type 19 model uses the transfer function coefficients. It should be noted that these coefficients should not include radiative resistance at the inside surface. Therefore the standard ASHRAE inside surface resistance E0 which includes both convective and radiative resistance should not be used. Because radiation is handled separately by TRNSYS, only an inside convective resistance of 0.1044 m^2-K-hr/kJ should be included when deriving the transfer function coefficients. This value should also be specified in the parameter list of Type 19, for calculating the sol-air temperatures. The standard ASHRAE external surface resistance A0, can be used as it is since the wind speed is used only to calculate the sol-air temperature.

Bansal and Bhandari (1996) have developed a software tool called ADMIT and used TRNSYS to simulate a building under similar weather conditions in order to evaluate the accuracy of their program. Simulations have been performed for three different climatic zones in India for light and heavy constructions under conditions of glazed/unglazed areas and ventilation rates.

2.4 Typical Meteorological Year for Nicosia-Cyprus

The general climatic conditions of Cyprus are mostly very sunny with an average solar radiation of 5.4 kWh/m^2 per day on a horizontal surface (Petrakis *et al.*, 1998). This radiation is among the highest in the world and the solar energy input is particularly high during the dry summer that lasts from April to October. During the rest of the year, sunshine duration remains considerable even in the coldest months. All tests are carried out in Nicosia-Cyprus. For this reason a Typical Meteorological Year (TMY) for this area is necessary. Petrakis *et al.* (1998) have generated the TMY from hourly measurements, of solar irradiance (global and diffuse on horizontal surface), for a seven year period, from 1986 to 1992. The measurements were performed by the Meteorological Service of the Ministry of Agriculture and Natural Resources of Cyprus, at the Athalassa region, an area located to the suburbs of Nicosia. Athalassa is at a latitude of 35°09', longitude 33°24' and 162 m high, above the mean sea level.

3. THE CYPRUS HOUSES

The present trend in residences is to construct very large houses, well in excess of the needs of the occupants with a lot of impressive elements for decoration, which are unfortunately environmentally incorrect.

The construction method applied nowadays is basically the same all over Cyprus. The bearing structure of a building, which may be either a large multi-storey building or single-storey one, consists of the foundations, the columns, the beams and slabs. The bearing structure is made of reinforced concrete. For the concrete mixture Portland cement, fine aggregate (sand) and coarse aggregate is used.

The walls are constructed from hollow bricks made from burnt clay, covered with plaster on both sides. The dimensions of the bricks are 30 cm by 20 cm by 10 cm. External walls have a thickness of about 25 cm and internal walls a thickness of about 15 cm. During the resent years, there is a trend to use cavity external walls, constructed of two brick walls with a layer of insulation of about 5 cm in-between, as illustrated in Figure 2. The total thickness of the insulated external wall is about 30 cm. The floors are made of concrete slabs, covered when needed with a layer of sand or screed of about 10 cm in which all plumbing and other services are placed, and finally the floor finish (usually tiles, marble, or granite blocks).

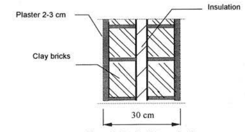


Figure 2. Detail of External wall.

Flat horizontal roofs, which constitute the majority, consist of the slab, usually 150mm in thickness, with an additional layer of plaster of 3 cm at the underside applied if the slab is not fair-face constructed i.e., smooth without irregularities at the underside. Usually the roof is water proved with a thin layer of bitumen and painted in white or aluminium colour on top. However during the resent years, the trend that prevails is to use an inclined, fair face slab, insulated very lightly and covered with a layer of mortar and roof tiles on top, without a false ceiling in the room (Figure 3). The reason for this method of construction is because it is simpler, does not need any special skills and is cheaper. Of course this method is environmentally incorrect, since the heat gains or losses increase with the increase of the roof area that does not have additional insulation or a false ceiling underneath.

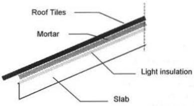


Figure 3. Detail of Roof construction.

The construction of the buildings results in a total weight of about 800 kg/m² of floor area.

3.1 Model House Construction

TRNSYS model 19 is used in order to simulate the temperature variation observed within a model house in Nicosia-Cyprus. To simplify calculations, a house with the external characteristics and area of those encountered in Cyprus is considered with any heat loss or gain between partitions. The model house illustrated in Figure 4, has a floor area of 196 m² and consists of four identical external walls, 14 m length by 3 m high, with a total window opening of 5.2 m on each wall. The window area is approximately equal to the area that a typical house would have, but instead of considering a number of single windows on each wall, only one window is considered with a total area equal to the total area. Since the same model will be used in evaluating the load for various constructions this simplification is not important.

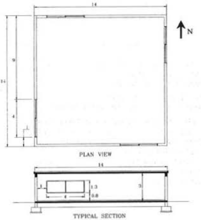


Figure 4. Model house architectural drawing.

4. RESULTS

This section presents the results of the simulations obtained by TRNSYS and the TMY weather file. Two parameters are investigated, the inside temperature and the energy consumption, resulting from various building constructions of the model house.

4.1 Standard construction methods

The houses in Cyprus are usually built with hollow bricks made of fired clay.

The usual density of these bricks is 940 kg/m^3 with a thermal conductivity (k) of 0.243 W / m K, for a temperature difference of 15°C (20 – 35°C). Since the thermal conductivity varies with the temperature, a check of its effect on the model house temperature variation is performed. Figure 5 shows the temperature variation through three consecutive days in early February. The wall construction of the two cases tested is exactly the same (0.2 m single hollow brick wall with 0.02m plaster on each side) but a thermal conductivity of 0.243 W / m K was used in the first case and 0.4 W / m K was used in the second.

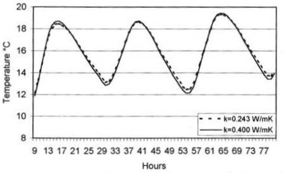


Figure 5. Temperature variation of the model house for three consecutive days in early February

As it is seen a very slight difference of the temperature between the two results, with a maximum of 0.3°C. The same variation of temperature between the two cases is observed throughout the year. This means that the wall brick thermal conductivity is not an important factor.

The response of the model house during the hours of a typical year is shown in Figure 6. The temperature varies approximately between 10-20°C during winter and raises to 30-45°C during summer.

The cooling and heating load resulting from every element of the model house is summarised in Table 1. As it is observed the main load is due to the roof construction which must be well insulated. Concerning the wall orientation, the cooling load is higher for the East and South walls which receive and transfer inside the house, more solar heat during the hot hours of the day. The heating load is higher for the North and West walls since they receive and transfer less solar heat during the day. The floor of the model house in this case was not considered to be a partition. Instead, from our observations, the ground temperature was assumed to very between 16 and 22°C, in relation to the ambient temperature.

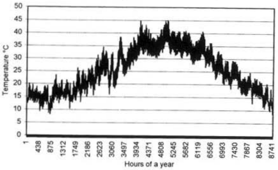


Figure 6. Temperature variation of a typical house for each hour of a typical year.

This variation may be presented by:

$$Tgr = 16 + (Ta / 7)\ ^{\circ}C \quad (3)$$

where:

Tgr = ground temperature (°C)

Ta = ambient temperature (°C)

Also the actual floor type as constructed in Cyprus was used in the TRNSYS calculations. This type of floor was considered to consist of 10 cm heavyweight concrete, 5 cm of compacted sand, 5 cm of plaster, 2 cm of marble floor finish and the inside air resistance.

Table 1. Cooling and heating load, arising from every constructional element of the model house.

House Element	Cooling Load (kWh) for 25°C	Heating Load (kWh) for 21°C
South Wall	1570	491
East Wall	1880	470
North Wall	1395	627
West Wall	1395	606
Floor	8140	1974
Roof	13736	5094
South Window	323	569
East Window	316	574
North Window	317	572
West Window	319	567
Other	1667	1224
Total	31058	12768

The load from the windows, shown in Table 1, is about the same irrespective of the window orientation. The reason for this is that the transmitted solar and thermal energy is calculated internally, considering that this energy is striking the floor.

By checking various wall construction methods used in Cyprus, their effect on the house temperature can be observed. The investigation is performed for the following three cases:

(a) 0.2 m single hollow brick wall with 0.02m plaster on each side,

(b) double-wall with 0.1m hollow brick and 0.02m plaster on each side and a layer of 0.025m insulation in between, and

(c) double-wall with 0.1m hollow brick and 0.02m plaster on each side and a layer of 0.05m insulation in between.

It must be noted that in all the above cases a non-insulated roof, constructed from fair-face 0.15m heavy concrete was assumed. The results indicate that the wall type is not of any importance as during the whole year (Figures 7 & 8) the temperature variation in the model house is extremely small.

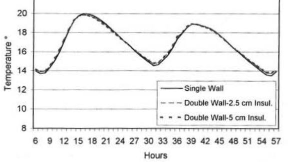


Figure 7. Temperature variation for various wall constructions in early January

This of course does not mean that the wall insulation is completely useless. The variation of the heating load can be seen in Figure 9, where the heating load is plotted for the hours of a typical January day, in order to keep the inside temperature at 18°C and 21°C, for various wall constructions. As it is seen, a reduction of the heating load of a maximum of 0.5 kWh results in every case.

The value of the wall insulation is better understood if the heating and cooling load is calculated throughout the year and summed in order to evaluate any savings. The results, for keeping the temperature in the range of 18-25ÆC and the humidity ratio between 0.005-0.008 (kg water/kg dry air) are indicated in Table 2.

Thus for keeping the temperature at 25°C, a cooling load of 31065 kWh is needed for the single wall construction. A load reduction of 1.4% results for a double wall with 2.5 cm insulation and a reduction of 2.1% results for a double wall with 5 cm insulation. The heating load presents a reduction of 5-7% for a double wall with 2.5 cm insulation and a reduction of 8-10% for a double wall with 5 cm insulation for maintaining the house temperature at 18-21ÆC. It is also important to note that in increasing the house temperature from 18°C to 21°C, the heating load is more than doubled.

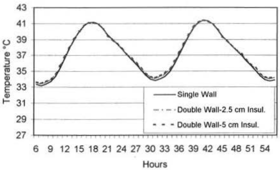


Figure 8. Temperature variation for various wall constructions in mid July.

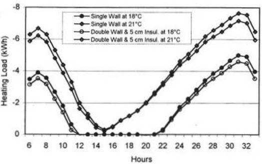


Figure 9. Heating Load against Time (hours) for a typical January day in order to keep the inside temperature at 18°C and 21°C.

Subsequently, the importance of the roof construction is evaluated. For this test, runs are performed for a 0.2 m single hollow brick wall with 0.02m plaster on each sight and the following three variations:

(a) a non-insulated roof, constructed from fair-face 0.15m heavy concrete,

(b) insulated roof, constructed from fair-face 0.15m heavy concrete and 0.025m polystyrene insulation, and

(c) insulated roof, constructed from fair-face 0.15m heavy concrete and 0.05m polystyrene insulation.

The temperature variation inside the model house can be observed in Figure 10. As it is seen, a major saving can result for insulating the roof since there is an increase in the room temperature of a maximum of 3°C during winter for an insulated roof and the temperature variation in this case is closer to the required room temperature.

Table 2. Cooling and Heating Loads for keeping the model house at various room temperatures.

Load	Single wall	Double wall with 2.5 cm Insulation		Double wall with 5 cm Insulation	
	(kWh)	(kWh)	% load reduction	(kWh)	% load reduction
Cooling at 25°C	31065	30620	1.4	30420	2.1
Heating at 18°C	5966	5557	6.9	5380	9.8
Heating at 19.5°C	9030	8485	6.0	8246	8.7
Heating at 21°C	12775	12078	5.5	11765	7.9

During summer (Figure 11), the insulated roof does not allow the room temperature to exceed 37°C while the non-insulated roof allows the temperature to rise up to 41°C i.e., a significant reduction in the load is obtained. A closer look on the cooling and heating loads for various roof constructions, for keeping the model house at various room temperatures is indicated in Table 3.

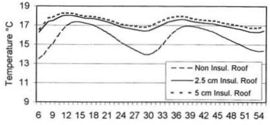


Figure 10. Temperature variation for various roof constructions in early January.

Thus for keeping the house temperature at 25°C, a cooling load of 31065 kWh is needed for the single wall construction. A load reduction of 38.3% results for a roof insulation of 2.5 cm and a reduction of 46.6% results for a roof with 5 cm insulation. The heating load presents a reduction of 62.3% for a roof with 2.5 cm insulation and a reduction of 72.9% for a roof with 5 cm insulation, for maintaining the house temperature at 18°C. Maintaining the model house at 19.5°C, a saving of 55.3% results for 2.5 cm insulation and 65.6% for 5 cm insulation. At 21°C the respective saving is 50.3% for 2.5 cm insulation and 60.2% for 5 cm insulation.

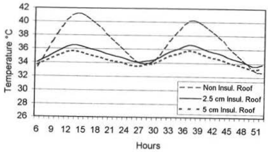


Figure 11. Temperature variation for various roof constructions in end of July.

Table 3. Cooling and Heating Loads for various roof constructions, keeping the model house at various room temperatures.

Load	Single wall no-Roof Insulation	Single wall with 2.5 cm Roof Insulation		Single wall with 5 cm Roof Insulation	
	(kWh)	(kWh)	% load reduction	(kWh)	% load reduction
Cooling at 25°C	31065	19170	38.3	16590	46.6
Heating at 18°C	5966	2249	62.3	1619	72.9
Heating at 19.5°C	9030	4034	55.3	3102	65.6
Heating at 21°C	12775	6353	50.3	5079	60.2

4.2 Effect of Mechanical Ventilation

All the above cases were considered without any mechanical ventilation to the space. Subsequently the effect of introducing mechanically, ambient air into the space when the outdoor air is of lower temperature than the indoor during summer and vice-versa during winter is investigated. For luxury apartments 1.7 l/s per m^2 of floor area is recommended (Handbook of Air Conditioning System Design, Carrier, 1965). This amount corresponds to 1500 kg/h of ventilation air, for the model house. The effect on the house temperature that this amount of ventilation air will have, when the outside temperature is greater than the house temperature in winter, is negligible. In summer when ventilation air is introduced into the house when the outside temperature is less than the house temperature, the effect is of some value. This result is indicated in Figure 12, where in July the temperature of a 0.2m brick house without insulation, can reach 44°C, while with ventilation its temperature will be less by about 1 to 2°C.

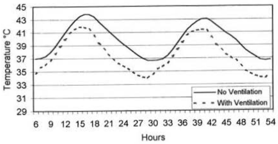


Figure 12. The effect of ventilation by the end of July, for a model house of 0.2m brick without insulation.

Checking the effect of ventilation in various air-conditioned model houses, and allowing ventilation air to enter the house when in winter the outside temperature is higher than the house temperature and vice-versa in summer, the results indicated in Table 4 are obtained. As it is seen, in winter there is no appreciable effect. In summer this leads to a saving of about 2.9 to 7.6%.

Table 4. Cooling and Heating Loads for various roof constructions, with mechanical ventilation.

	Single wall no-Roof Insulation			Single wall with 2.5 cm Roof Insulation			Single wall with 5 cm Roof Insulation		
	(kWh)		%	(kWh)		%	(kWh)		%
Load	With ventilation	Without ventilation	load reduction	With ventilation	Without ventilation	load reduction	With ventilation	Without ventilation	load reduction
Cooling at 25°C	30171	31065	2.9	18417	19170	3.9	15329	16590	7.6
Heating at 21°C	12756	12775	0.1	6348	6353	-	5075	5079	-

4.3 Inclined Roofs

Finally the effect of constructing an inclined roof instead of the traditional flat roof, is examined. This is a construction mostly applied nowadays in Cyprus mainly due to aesthetic reasons. As it is seen in Table 5, the inclined roof results in an increase of load between 4.1 and 9.1% depending on its orientation and time of year, when constructed in the same way as the flat roof. It must be noted though that for the inclined roof the typical construction is 15cm heavyweight concrete, 4mm water proofing with 5cm plaster and clay tiles on top. This construction, used as a decorative element, is an imitation of the traditional roof and results in a reduction of the air-conditioning load of 19.2-25.7%.

Table 5. Cooling and Heating Loads for Flat and Inclined Roofs.

Load	Flat concr. roof, no insulation	N-S, 20° Inclined roof				E-W, 20° Inclined roof			
		(kWh)				(kWh)			
	(kWh)	Concrete roof, no insulation	% Load increase	Tile, plaster and insulation on concrete roof	% Load decrease	concrete roof, no insulation	% Load increase	Tile, plaster and insulation on concrete roof	% Load decrease
Cooling at 25°C	31065	32325	4.1	24553	21.0	33239	7.0	25101	19.2
Heating at 21°C	12775	13942	9.1	9677	24.2	13635	6.7	9488	25.7

5. ECONOMIC ANALYSIS

Applying the life saving analysis method for the various constructions studied, the results indicated in Table 6 are obtained.

As it is observed the double wall construction nearly pays back the initial capital expenditure. Looking at it from the environmental point of view and the saving in fuel, which is imported, it is advisable to be done. The main load in the building comes from the roof therefore its insulation results in large savings, ranging from C£ 6770 to C£ 8680 for a 20-year period. It should be noted that these numbers refer to savings in fuel and electricity when the building is conditioned at all hours of the year.

Table 6. Saving in C£ for cooling at 25°C and heating at 18/EC, 19.5°C and 21°C for a 20 year period.

Heating temperature (°C)	Double wall with 2.5cm Insulation	Double wall with 5cm Insulation	Single wall with 2.5cm Roof Insulation	Single wall with 5cm Roof Insulation
18°C	-83	-92	6770	8074
19.5°C	-58	-56	7002	8361
21°C	-30	-15	7260	8681

6. CONCLUSIONS

The objective of this work is to investigate the heating and cooling load variation for various building constructions encountered in Cyprus. This is achieved using the TRNSYS program, which performs the above analysis by employing the transfer function method. For the calculations, a Typical Meteorological Year for the Nicosia area and a typical model house are used.

The results indicate that the inside house temperature, when no air-conditioning is used, varies between 10-20°C for winter and between 30-45°C for summer. The evaluation of the heating and cooling loads for various wall and roof constructions indicates the importance of the roof insulation, which results in a reduction up to 47% of the cooling load and up to 73% of the heating load. Also the effect of mechanical ventilation is examined. Air is allowed to enter the house, when in winter the outside temperature is higher than the house temperature and vice versa in summer. This analysis indicates that in winter there is no appreciable effect whereas in summer it leads to a saving of about 2.9-7.6%. The effect of the inclined concrete roof used for aesthetic reasons is also examined. This construction decreases the energy consumption because of its heavy construction.

Finally a feasibility study is presented. The life cycle cost analysis is used for the economic analysis of the various constructions. The results indicate that the wall insulation pays back in a twenty years period whereas the roof insulation has considerable economic benefit with a life cycle savings of C£6770 up to C£ 8680 depending on the room temperature and the insulation thickness.

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IDENTIFYING CUSTOMER SATISFACTION: NATIONAL QM SURVEYS IN CYPRUS SERVICE SECTOR

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INTRODUCTION

Nowdays the interest of quality is growing all over the world; customers and users are becoming more and more demanding. They are no longer willing to accept inferior quality of any products or services provided to them. In today's competitive market, no business can survive without satisfied customers [Stamatis D.H, 1996]. Therefore, in the run to the new millenium, managers have to focus on the right priorities. Provided that Cyprus will join the European Union (E.U) in the next few years, the Cyprus industry in general must be greatly improved in order to compete with other European countries.

The main objective of this Joint venture investigation was to demonstrate how identification and analysis of customer requirements was made through national surveys in the service sector and suggest ways that the senior management can encompass in order to satisfy these requirements. It will also show ways and methodologies that can be used in similar cases on how to execute national surveys, analyze results, present results and identify the most important parameters or customer requirements using the technique of Quality Function Deployment (QFD).

The study investigated the potential of improving the performance of the Cyprus hotel and banking industry, by carefully identifying the customer requirements and the degree of their importance. A second important objective was to investigate how well the different hotels and banks in Cyprus are satisfying these needs and comparing them with the target value (customer importance). The whole investigation is considered the first stage for the Total Quality Management (TQM) implementation, which is the 'Diagnosis Phase'. Improvements on the performance of any industry can be successful (at the implementation stage of TQM) only after the needs of the customers and the quality levels offered by the hotels have been identified and correctly evaluated. Differently expressed, this means 'trying to close the gap between the two'. By identifying the needs of the customers and the quality levels of the organizations, allows recommendations for actions to be taken and long-term plans for implementation of quality programs

RESEARCH METHODOLOGY

There are a large number of research methods and texts available, some of them dedicated specifically to the service fields. Individual authors have their own way of approaching the research process and therefore no single text can hope to cover all the cases. According to various authors [Slack M. et al, 1993] and [Ryan C., 1995] the best method of conducting a survey and collecting information on facts and opinions from large number of people, is to produce a questionnaire. This was the method that was adopted.

While all service industries share common characteristics, some aspects of the relationship between an organization and its customers are complex and unique. There are two main components of Total Quality in service: service quality and customer care.

Bearing in mind the aims of the research study, it was necessary to design different questionnaires targeting to different people and different objectives. Very briefly each of these questionnaires includes the following for the hotel sector:

(a) A Questionnaire addressed to hotel managers: 43 questions (in the great majority closed-ended) addressed to 28 managers, covering all aspects of TQM: people, tools and systems.

(b) Customer importance questionnaire: Addressed to 30 customers, asking them to rate on a seven-point scale, the relative importance for 19 Key factors (attributes) given, related to customers staying in hotels.

(c) Customer satisfaction questionnaire: Addressed to 30 different customers, asking them to rate, on a seven-point scale, their relative satisfaction with their stay at the hotels of Cyprus, for the 19 Key success factors previously ranked.

For the banks cector an extensive literature search was made focusing on research and studies of academics and practitioners. Seventeen 'whats' (customer requirements) and 50 'hows' (ways that the management can do in order to satisfy these requirements) were identified. The 17 'whats' customer requirements were used as the basis for the questionnaire of a survey directed to over 80 customers from all levels of society in Cyprus. The grading of those requirements was used as a weighted factor in analysis of the factors prioritising the immediate action that should be taken by senior management, which was accomplished using Quality Function Deployment (QFD) approach. Published material that related specifically to the investigation was relatively easy to obtain from learning resource centers, CD-ROMs and past surveys.

The proper design and layout of those questionnaires was therefore of paramount importance since it was the major vehicle for providing data. The formulation of the management questionnaire was largely influenced by the questionnaire used in a previous National study conducted in 1993 [Angeli I., 1993]. Meetings with the bank management and senior officers from the CTO (Department of statistics) were arranged in order to discuss the 'WHATs' and the 'HOWs' and give their own opinion and views in order to prepare a final tree diagram with all the WHATs, HOWs and their interrelations. This was used as a guide when the data was inputted in the QFD matrix.

Once the draft questionnaires were prepared, a pilot implementation was conducted to enable the authors to test the reliability, suitability and effectiveness of the questionnaires. The suggestions of the managers were taken into account and changes were made regarding the layout, length and suitability of some questions.

For the customers there was no selection. A random sample of about 60-100 (Depending on the case) was given a questionnaire to answer. The customers were from different banks or hotels covering the whole island. The customers were asked to grade the key requirements in a scale of 1 to 7 indicating the importance they pay to a particular parameter. On the same questionnaire they were asked to evaluate how satisfied they were (with respect with the same parameters) with their bank or hotel.

The sample size is of vital importance in any national survey especially if you are dealing with a very large population. So is recommended to reduce the original number using certain rules. An example is given for selecting the sample size for the management questionnaire. After meeting senior officers from the CTO (Department of statistics) they recommended to exclude the no- star to 2 stars hotels from the survey. So the population of the hotels reduced from total 534 to 150. Further reduction to 28 (total sample) was made using the stratified random sampling technique shown in Table 1. This technique was used to ensure a representative sample of the population under study (i.e. the 150 units), with respect to stars, location and area.

The surveys were conducted over a two-week period in July 1998. The returned mail (hotel management) and personal interview (customers) was used as a work tool.

Table 1: Selection of sample size by area and hotels stars

POP./SAMPLE AREA	Population *****	Sample *****	Population ****	Sample ****	Population **	Sample ***	Total sample
NICOSIA	1	1	3	1	4	1	3
LIMASSOL	6	1	10	1	18	3	5
LARNACA	1	1	5	1	7	1	3
AGIA NAPA	3	1	7	1	23	3	5
PARALIMNI	1	1	8	1	10	2	4
PAFOS	5	1	11	2	19	3	6
HILL RESORT	-	-	1	1	7	1	2
TOTAL	17	6	45	8	88	14	**28**

RESULTS PRESENTATION AND ANALYSIS

Presentation of results is of vital importance. They should be clear, accurate, consistent and understandable by the people the report is addressed. It is important to use the right tools, form or layout to present the results (fitness for purpose) i.e. bar chart, table, gap analysis, tree diagrams, multi attribute diagrams etc. In the following pages some of the results will be shown. Different methods for presenting data will be used.

For the presentation of the answers of the hotel management questionnaire, 'component bar charts' were mainly used in order to show the contribution for each of the classes of hotels to the total. It must be noted that these types of bar charts, represent proportional values rather than raw numeric data. In the case of the results of the 17 key banks customer requirements from the customer survey a table was used to summarise the results shown in Table 2. The most significant results concerning each question individually, and the differences between the target values and the level of the different banks are shown in detail. The results are confidential that is why the names of the commercial banks are not shown. They are compared only with the co-op bank. The detail results were sent to the banks on request. It is obvious that all banks are below the target value (customer expectations) in the great majority of the parameters. It seems co-op banks are doing well compared with commercial banks, at least on the services they offer. The results for each question parameter in both surveys are shown in detail in bar-chart form on the main reports (Zarvos G. 1998, Economides A. 1998).

Apart of the summary table in the main report, a Multi-attribute diagram was used for analysis of the hotel results consisted of two components: what do customers think is important with their stay to a hotel, and to what extend this has been achieved in the hotel they were staying in Cyprus, or customer satisfaction. Therefore the tabulated results explained before permit a simple diagrammatic representation to be set out, where the axes are the universal scores of importance and satisfaction with their stay. It then becomes possible to plot the approximate locations of the attributes in the four quadrants. The advantage of this diagram, shown in Figure 1, is that it reinforces the results in a way that might otherwise be lost in a table. The importance of the use of the diagram is evident from the foregoing discussion. It quantitatively analyzes what is important to customers, how the customers perceive the services delivered by the hotels, and on what attributes hotels' resources can be best spent for improvement. The analysis also permits the use of gap analysis as possibly a measure of satisfaction or dissatisfaction. If satisfaction is a balance between perceived attributes of a desired stay, and the actual attributes of a stay, then where the actual experience falls short of a desired experience, a level of dissatisfaction might be said to have occurred. Many lessons can be learned from this diagram; Hotel managers should concentrate on quadrants 1 and 2 where the importance of factors is high for customers and at the same time they can see how well they are meeting the expectations of their customers i.e. how much they are above or below the horizontal axis.

Table 2: Customer satisfaction survey in banking sector

	CUSTOMER SATISFACTION SURVEY IN BANKING SECTOR						
RANK	CUSTOMER KEY REQUIREMENTS	TARGET	Bank A	Bank B	Bank C	Coop. BANK	Others
1	Promptness of service	6.75	4.90	5.08	5.58	5.30	4.60
2	Attitude of staff	6.51	5.43	5.47	5.83	5.50	4.90
4	Fair treatment	6.30	5.08	5.24	5.46	5.63	4.80
17	Availability of products and services	5.09	5.55	5.66	4.63	5.19	4.30
3	Reliability of service	6.36	5.71	5.63	5.60	5.38	5.60
7	Product knowledge	6.13	5.51	5.32	5.33	5.50	4.80
12	Amount of charges	5.93	4.12	3.89	5.55	4.81	4.10
6	Hand. problems, complaints	6.17	4.71	4.84	5.50	5.13	4.20
8	Practices and procedures	6.01	4.84	4.76	5.03	5.13	4.30
10	Professionalism of staff	6.00	5.06	5.24	6.48	5.56	4.70
8	Privacy	6.01	5.35	5.37	5.53	5.31	4.80
13	Presentation of branches	5.92	6.08	6.00	6.03	5.63	5.60
14	Presentation of staff	5.39	5.84	6.03	6.05	6.06	5.40
15	Presentation of advertising material	5.37	5.33	5.29	4.50	5.06	4.70
5	Accessibility to the branch	6.21	4.55	4.66	4.73	4.75	4.70
11	Security	5.95	4.86	4.74	4.70	5.13	5.10
16	Accessibility to the management level	5.32	4.84	4.79	5.33	4.50	4.60
	Total Average for Banks	**5.97**	**5.16**	**5.18**	**5.40**	**5.27**	**4.78**

Similarly a simple diagram can express that idea possibly better than tables or Bar charts ('Difference' column) to identify the difference in mean scores. This is shown in Figure 2, where the mean score of importance and satisfaction for each attribute is simply drawn by a line. The lines are interpreted as follows: the lines, which have positive slope, indicate satisfaction (shown with continuous lines) while lines with negative slopes indicate dissatisfaction (shown with dotted lines). The greater the slope, either positive or negative, the greatest the level of satisfaction or dissatisfaction respectively. It is clearly shown on Figure 2 that the top 6 important factors for customers the Cyprus hotels are short. So this is a good point where managers could start their improvements.

The graph clearly indicates that factors such as, 'clean rooms', 'quality of food', 'friendly' which are all placed in Quadrant 2 (i.e. very important and highly satisfied) show a negative slope. Expressed differently, hotels cannot meet the most important requirements of their customers.

What also emerges from the graph is that customers are mostly dissatisfied with 'quick service'. Bitler [Johnson P., Thomas B, 1993] reports on this: 'of a total of 180 complaints they record in hotels 38% fell into the category of unprompted and unsolicited employee actions'. It is advisable to compare or confirm the results of a new survey with other survey results executed in the past in Cyprus and abroad, if any. The Hotel results confirm the results of a previously quoted study [Saleh F., Ryan C., 1992]. Clean rooms, quality of food, friendly staff, location, quick service and overall value are of high importance to the customers no matter who are they and where they coming from. A comparison between the two studies is shown in Table 3. Analysis of the two studies indicates that both tangible and intangible attributes of the hotel product are of importance to the customers. 'Clean rooms' is clearly the most important element.

A first brief comment to make is that hotel customers' satisfaction of the services provided is moderately good, at 5.549 on the seven-point scale. Satisfaction seems to be highest with the tangible components of the service, such as 'clean rooms' and 'wake up call', but lowest with the intangible elements, such as 'quick service' and 'individual attention'. A possible explanation is that for the management of the hotels it is easier to correct problems related to tangible components, but training, monitoring and evaluation of the staff is more difficult.

When managers were asked to rate how much their customers' are satisfied with their hotels a mean value of 5.980 was estimated. Comparing this value with the universal satisfaction value of customers was 5.549; it can be also argued the managers overestimate customers' perceptions. This is very usual in this kind of surveys in all countries.

Table 3: Comparison of two studies (Cyprus & UK) for customer importance in hotel Industry

ATTRIBUTE	AVERAGE IMPORTANCE FOR:	
	CURRENT STUDY	PREVIOUS STUDY
Clean rooms	6.348 (1)	6.790 (1)
Quality of food	6.174 (=2)	6.160 (8)
Friendly staff	6.174 (=2)	6.132 (9)
Location	5.909 (3)	6.384 (6)
Overall value	6.000 (4)	6.342 (5)
Quick service	5.565 (5)	6.286 (7)
Quiet stay	5.545 (6)	6.664 (3)

Note: 1. The numbers in brackets indicate the ranking order

2. For the previous study: sample size- 145, number of attributes- 3

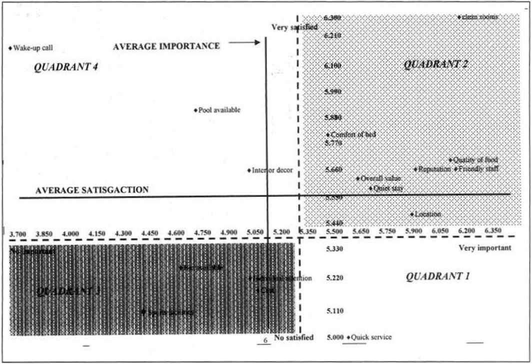
Once the customer needs have been identified and evaluated/ prioritized a methodology should be followed to fulfill and satisfy those needs. A very good way to understand and satisfy the customer needs is Quality Function Deployment (QFD). QFD is a quality improvement tool that is based on obtaining customers needs by directly interviewing them. It is a design tool that matches customers with the necessary corresponding systems design elements. This approach gives increased focus and resolution to understanding customers' requirements. Furthermore, the results can be used to prioritize the most important design elements, enabling efforts and resources to be concentrated on improving those that most effectively meet customers' needs. A short scale QFD exercise was used in the Hotel industry whereas a larger one was used in the Banking sector, which is demonstrated in the following pages, fugure 3.

The Importance Rating is useful for prioritizing efforts and making trade- decisions. Numerical tables and graphs were used for the development of the QFD matrix shown on Figure 3. The 'what' importance rating was established in this case based on the customer assessment with a scale of 1 to 7. The results were taken from the survey and they are showed on Table 2.

Action can be taken only from 'hows', so important rating for these 'hows' is needed. This is calculated as Importance Rating by QFD exercise. Weights are assigned to the Relationship Symbols: Strong=9, medium=3, weak=1. The 9-3-1 weighting achieves a good variance between important and less important items.

These values have no direct meaning, but rather must be interpreted by comparing the magnitudes to each other. These values give a guideline in order to help the analyst to decide which are the most important hows and to proceed in making improvements and recommendations. They will help management pay more attention to ways of improvement.

Figure 1: Multi-attribute diagram showing the approximate locations of the attributes



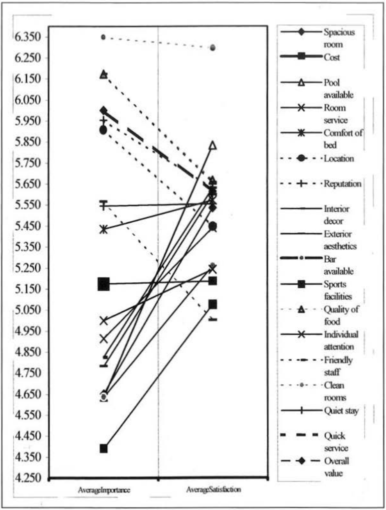


Figure 2: 'Gap analysis' for individual attributes in hotels

starting first with high values of importance. Also, a comparison between the performance of each bank individually according to the target value (the first column of the questionnaire, how important are the requirements for the customers) was shown on the matrix.

All the results of the QFD exercise were presented in such a way as to facilitate understanding and interpretation of results. The approach could lead to important results for decision-making and strategies that banks can follow towards improvement and competitive advantage as well as customer satisfaction.

CONCLUSIONS AND RECCOMENTATIONS

The introduction of Cyprus to the European Union in the nearby future will raise the need of the Cyprus service industry to compete with European ones, some of them, which are probably of world class. In other words, it will increase the competitive pressure by bringing more entrants to the Cyprus market. It will also exert a strong influence on customers' expectations and options. In that sense the performance of Cyprus organisations will be greatly affected by the high and consistent service levels and brand names of organisations chains with worldwide operations. This perspective implies that Cyprus Managers need to know whether the qualities of their services are comparable with those of European hotels. To answer these critical questions, small-scale surveys were conducted where the managers and their customers were asked, through the same questions, to give their opinions. The results were presented before so the overall conclusions will be written separately for each sector.

a) Hotel sector

The results of the research first revealed serious gaps between customers' perception and customers expectations (especially on the top 5) as well as between management perception and customers' perception of the services provided. Those points are particularly serious, since the research has shown the importance of customer satisfaction. In general the assessment from managers, of the total quality of the hotels was higher compared with that the customers. The above exposed a series of factors directly responsible for the quality problems in the Cyprus hotel industry:

The main problem of Cyprus hotels is in human resources. There is a minimum effort in training and educating and only slightly human resources management systems available that generates involvement of the employees in the hotel quality related activities. Therefore, the absence of either system for measuring staffs' needs, expectations and level of satisfaction based on its performance should not cause surprise.

Management shows little interest in undertaking quality improvement programs. They also ignore their fundamental role to inspire and guide in the necessary cultural change towards total quality. The lack of belief concerning total quality as a main method for continuous improvement has become evident in their absence of commitment, little participation of the suppliers in improvement projects and important mistakes in recognition of efforts and achievements of individuals.

The report is unique, in the sense that it is the first time such a study was conducted in the service industry of Cyprus, investigating both management/owners and customers. It can therefore be useful to those who want to follow the same path for research or even for hotel managers that are interested for improving the performance and services of their hotel.

b) Banking sector

QFD is relatively new for Cyprus and it is time that the senior management of banks begins to consider it. As was mentioned earlier, and as it is shown from the results, QFD is a requirement. Key benefits to this approach are product improvement, increased customer satisfaction, and increased market share.

Seventeen customer requirements (WHATs) were identified through the literature research, with the help of bank officials. Conducting the customer satisfaction survey, these seventeen customer requirements were evaluated. The top 10 factors from the survey are shown on table 4. Fifty ways of how to satisfy the customer requirements (HOWs) were identified through literature research (also bank officials consultation), using a tree diagram. These 'hows' were grouped and inputed on the QFD matrix. Relationships were inputed in order to show the relationship of 'hows' with each 'what'. If a team was existed then the study could be much more reliable and easier to complete. In this exercise were filled by the author, since there was no teamwork.

The relationships were then calculated with the importance ratings of the customers giving some values as to which 'hows' need to be prioritized. Also with those important 'hows' the great majority of 'whats' could be addressed. The top 10 factors prioritized in rank order are summarised below in Table 4, and recommendations for improvements were given. Numerical evaluations, ranks and orders, should only be used as a guideline in order to help the analyst to decide which are the most important factors and to proceed in making improvements since there are a lot of other aspects that should be look at, like cost, time etc.

Table 4: The top 10 Customer Requirements from the survey and the top 10 how those requirements can by implemented

RANK	TITLE OF WHATS	TITLE OF HOWS
1	Promptness of service	Training (on-going) /Expertise of staff
2	Attitude of staff	Communication with customer
3	Reliability of service	Empowerment of staff
4	Fair treatment (preferences)	Clientele/type of customer
5	Accessibility to the branch	Suitability of equipment
6	Handling problems, complaints & difficult situations	Knowledge of operational procedures
7	Product knowledge	Time of service
8	Practices and procedures =	Use of IT (information Technology)
9	Privacy =	Product Knowledge
10	Professionalism of staff	Control of emotions

It is important to understand that the conclusions drawn by the authors represent only a small sample of the conclusions that the senior management of the banks can derive from this research report. It is up to the individuals to examine the data and adopt the procedures to their own needs and plans. The customer satisfaction surveys questioned 60-100 customers. In order to implement all the above mentioned, a lot of effort and time will be needed. This is a team exercise with members carefully selected, as to be able to handle the situation effectively, efficiently and economically.

To conclude, the development of new systems enable one to evaluate the quality activities of the Cyprus service industry is therefore coming forward as promising area for research. It is of undoubted usefulness, owing to its absolute contribution to profitability and customer satisfaction. However, management must place it well in their minds that for a organisation to exist and flourish, everyone must internalize the concept that quality is a journey, not a destination. Service industry in Cyprus is good enough as perceived by the customers, but it should always be remembered that the basic principle of TQM is 'continuous improvement'. There is always room for that, for the service industry, which is considered the most important sector to the Cyprus economy.

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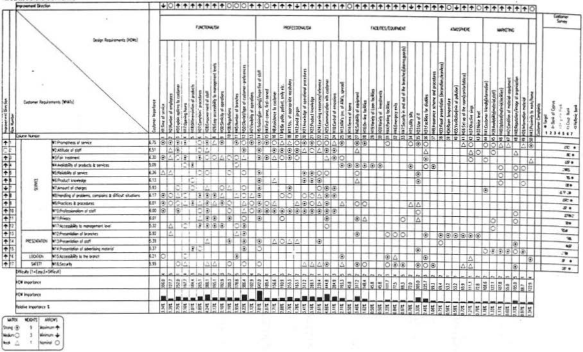
FIGURE 2: CUSTOMER SATISFACTION IN BANKING



MODELLING OF A THERMOSYPHON SOLAR WATER HEATING SYSTEM AND MODEL VALIDATION

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ABSTRACT

A thermosyphon solar water heater consisting of two flat plate collectors of total aperture area of 2.7 m^2 and 150-lt storage tank is modelled using TRNSYS. Simple experiments were conducted in order to validate the model. During the experiments the weather conditions were measured every 10 minutes and integrated over an hour together with the temperature of the water in the storage tank measured at the beginning and end of the day. These temperatures were used to validate the model by using the actual weather data as input to the program. Validation tests were performed for 25 days and the mean deviation between the predicted and the actual values of water temperature rise is 4.7% which is very satisfactory.

1. INTRODUCTION

Cyprus has no natural oil resources and relies entirely on imported fuel for its energy demands. The only natural energy resource available is solar energy. Cyprus has a very sunny climate with an average annual solar radiation of 5.3 kWh/m^2-day (on a horizontal surface).

Solar water heating units are extensively employed in Cyprus. In fact the total number of units installed are such that constitute Cyprus to be among the leading countries in the world in this area. These units are mostly of the thermosyphonic type. This type of solar water heater consists of two flat-plate solar collectors having an absorber area between 3 to 4 m^2, a storage tank with capacity of 150 to 180 litres and a cold water storage tank, all installed on a suitable frame. An auxiliary electric immersion heater and/or a heat exchanger, for central heating assisted hot water production, are used in winter during periods of low solar insolation.

Because the manufacturing of solar water heaters and mainly that of the thermosyphon type has expanded rapidly in Cyprus, there is a need to study in depth and model this type of systems. It is also required to validate the model using simple physical experiments. In this way the model can be used to investigate the effect of design changes and therefore improve its performance.

Many computer software programs have been developed concerning the modelling and simulation of thermal systems. The most popular are WATSUN, TRNSYS and TSOL. As part of this study TRNSYS 14.2 is selected as the most appropriate because this program allows detailed analysis of all components of the system and it is widely accepted as giving accurate prediction of solar system performance.

Model validation studies have been conducted in order to determine the degree to which the TRNSYS program serves as a valid simulation tool for a physical system. It has been shown by analysing the results of these validation studies that TRNSYS program provides results with a mean error between the simulation results and measured results on actual operating systems under 10% (Kreider and Kreith, 1981).

The objective of this work is to model a thermosyphon solar water heater with TRNSYS and validate the model by performing a number of simple experiments.

2. LITERATURE SURVEY

There have been extensive analyses of the performance of solar water heaters, both experimentally and analytically by numerous researchers. A representative sample of them is shown here.

Gupta and Garg (1968) developed a model for thermal performance of a natural circulation solar water heater with no load. They represented solar radiation and ambient temperature by Fourier series, and were able to predict a day's performance in a manner that agreed substantially with experiments.

Ong performed two studies (Ong, 1974 and 1976) to evaluate the thermal performance of a solar water heater. He instrumented a relatively small system with 5 thermocouples on the bottom surface of the water tubes and 6 thermocouples on the bottom surface of the collector plate. A total of 6 thermocouples were inserted into the storage tank and a dye tracer mass flow meter was employed. Ong's studies appear to be the first detailed ones on a thermosyphonic system.

The study of Shitzer *et al.* (1979) was undertaken with the purpose of improving further the performance of a thermosyphonic solar water heating system by detailed understanding of the phenomena involved in system operation.

Kudish *et al.* (1985) in their study measured the thermosyphon flow rate directly by adapting a simple and well-known laboratory technique, a constant level device, to a solar collector in the thermosyphon mode. The thermosyphon flow data gathered were utilised to construct a standard efficiency test curve, thus showing that this technique can be applied for testing collectors in the thermosyphon mode. Also, they determined the instantaneous collector efficiency as a function of time of day.

Morrison and Braun (1985) have studied system modelling and operation characteristics of thermosyphon solar water heater with vertical or horizontal storage tank. They found that the system performance is maximised when the daily collector volume flow is approximately equal to the daily load flow, and the system with horizontal tank did not perform as well as a vertical one.

Hobson and Norton (1989) in their study developed a characteristic curve for an individual directly heated thermosyphon solar energy water heater obtained from data of a 30 days tests. Using such a curve, the calculated annual solar fraction agreed well with the corresponding value computed from the numerical simulation. Furthermore, the analysis was extended, and they produced a simple but relatively accurate design method for direct thermosyphon solar energy water heaters.

Shariah and Shalabi (1997) have studied optimisation of design parameters for a thermosyphon solar water heater for two regions in Jordan represented by two cities, namely Amman and Aqaba through the use of TRNSYS simulation program. Their results indicate that the solar fraction of the system can be improved by 10-25% when each studied parameter is chosen properly. It was also found that the solar fraction of a system installed in Aqaba (hot climate) is less sensitive to some parameters than the solar fraction of a similar system installed in Amman (mild climate).

3. DESCRIPTION OF THE SYSTEM

The system consists of two flat plate solar collectors, having a total surface area of 2.7 m^2 tilted at 40° from horizontal, a thermally insulated horizontal storage tank of 150 litres capacity and interconnecting piping. It also incorporates a cold water storage tank of 1000 lt capacity.

The construction of the solar collector is important and relative to the operation and efficiency of the whole system. The external casing of the collector is made of high corrosion resistant galvanised steel sheet, sprayed with aluzinc paint.

The casing is covered with a 4mm thick low iron single glass and sealed with a rubber gasket. The absorber plate is made of copper. High radiation absorption is achieved by the use of black fine matt finish on the copper surface, which has a high absorption coefficient. The underside of the absorber plate and the side casing are well insulated to reduce conduction losses with 50mm and 30mm fibreglass insulation respectively.

The two flat plate collectors are connected in parallel through the supply headers, each employing 12 evenly spaced parallel copper pipes 15mm in diameter embossed by semi-circular grooves formed in the flat plate absorber.

Hot water is stored in the 150 litre hot water storage tank. Great care has been taken in the design and production of the tank since it is the only part of the system, which is directly connected to all other parts. It is made of copper and is thermally insulated with polyurethane. It is also protected by a galvanised outer shell 0.6mm thick. The connections to the other parts of the system are made by copper pipes. In addition, the storage tank has an electric immersion element of 3kW for heating water in the event of low solar insolation. The specifications of the system are tabulated in Table 1.

Description	Value/Type
Total aperture area	2.7m²
Storage tank capacity	150 litres
Riser tubes material	copper
Number of riser tubes	12
Absorber surface	painted mat black
Glass type	4mm low iron glass
Collector insulation	fibreglass 30mm sides fibreglass 50mm back
Auxiliary heater	3kW electric element

4. MODELLING OF THE SYSTEM

The proper sizing of the components of a solar system is a complex problem which includes both predictable (collector and other performance characteristics) and unpredictable (weather data) components. In this section it is indicated how all the necessary components of the solar water heater can be formulated into a single model with the aid and use of TRNSYS simulation program.

Computer modelling of thermal systems presents many advantages the most important of which are the following:

1. Eliminate the expense of building prototypes.
2. Complex systems are organised in an understandable format.
3. Provide thorough understanding of system operation and component interactions.
4. It is possible to optimise the system components.
5. Estimate the amount of energy delivery from the system.
6. Provide temperature variations of the system.
7. Estimate the design variable changes on system performance by using the same weather conditions.

Simplified analysis methods have advantages of computational speed, low cost, rapid turnaround, which is especially important during iterative design phases, and easy of use by persons with little technical experience. Disadvantages include limited flexibility for design optimisation, lack of control over assumptions and a limited selection of systems that can be analysed. Thus, if the system application, configuration or load characteristics under consideration are significantly non-standard, a detailed computer simulation may be required to achieve accurate results.

The initial step in modelling a system is the derivation of a structure to be used to represent the system. It will become apparent that there is no unique way of representing a given system. Since the way the system is represented often strongly suggests specific modelling approaches, the possibility of using alternative system structures should be left open while the modelling approach selection is being made. The structure that represents the system should not be confused with the real system. The structure will always be an imperfect copy of reality. However, the act of developing a system structure and the structure itself will foster an understanding of the real system. In developing a structure to represent a system, system boundaries consistent with the problem being analysed are first established. This is accomplished by specifying what items, processes, and effects are internal to the system and what items, processes, and effects are external.

4.1 Procedure Followed

The thermosyphon solar water heater mounted in Nicosia, Cyprus was first modelled with TRNSYS program. In the program all the system characteristics are required like the collector performance indicators of slope and intercept of the standard collector test, dimensions of all components and piping, hot water storage tank size, distance between the various components of the system and many others.

The model was then simulated with weather data gathered at the location where the thermosyphon solar water heater under investigation is installed. These values were used in the TRNSYS program in order to predict the system performance. In order to validate the model the initial and end of day mean water temperature in the storage tank were also measured and the water temperature rise was used as a validation parameter. This procedure was conducted for a number of consecutive days for a few months. The outcome of the simulation process (predicted results) were then compared with the actual test measurements in order to determine the accuracy of the simulation program.

The temperature of the water in the storage tank was chosen to validate the model. This is because this temperature is a very important parameter both for the designer and for the end user. No draw off was considered to simplify the validation process and the auxiliary electric immersion heater remained off during the testing period. Also to take into account the storage tank stratification effects the top and bottom temperatures were measured and the mean of the two was considered as the mean storage tank water temperature. These temperatures were measured by drawing off a small quantity (about 1 litre) of water.

4.2 TRNSYS Simulation Program

TRNSYS is an acronym for a "transient simulation program" and is a quasi-steady simulation model. This program was developed by the University of Wisconsin by the members of the Solar Energy Laboratory (klein et al., 1994). It is written in ANSII standard Fortran-77. The program consists of many subroutines that model subsystem components. The mathematical models for the subsystem components are given in terms of their ordinary differential or algebraic equations.

With a program such as TRNSYS which has the capability of interconnecting system components in any desired manner, solving differential equations and facilitating information output, the entire problem of system simulation reduces to a problem of identifying all the components that comprise the particular system and formulating a general mathematical description of each.

Once all the components of the system have been identified and a mathematical description of each component is available, it is necessary to construct an information flow diagram for the system. The purpose of the information flow diagram is to facilitate identification of the components and the flow of information between them. Each component is represented as a box, which requires a number of constant PARAMETERS and time dependent INPUTS and produces a time dependent OUTPUTS. An information flow diagram shows the manner in which all system components are interconnected. A given OUTPUT may be used as an INPUT to any number of other components. A simplified information flow diagram for the thermosyphon solar water heating system under investigation is shown in Fig. 1.

From the flow diagram shown in Fig. 1 a deck file has to be constructed containing information on all the system components, weather data file, and the format the output is given.

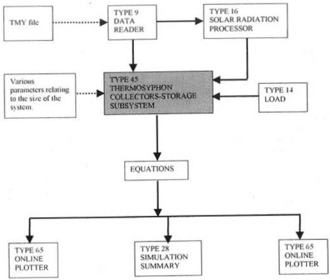

Figure 1. Information flow diagram for the thermosyphon solar water heating system.

Simulations generally require some components, which are not ordinarily considered as part of the system. Such components are utility subroutines and output producing devices. The TYPE number of a component relates the component to a Fortran subroutine, which models that component. Each component has a unique TYPE number. The UNIT number is used to identify each component (which can be used more than once) in the deck file. Although two or more system components can have the same TYPE number, each must have a unique UNIT number.

It is worth noting here, that the deck file reads information provided by the Typical Meteorological Year (TMY) weather data which was generated by Petrakis et al. (1998) for Nicosia, Cyprus. A copy of this file is modified by employing the actual weather data of the days where the experiments were performed and used for the program validation.

4.3 TYPE 45: Thermosyphon Collector Storage Subsystem

This component models the thermosyphon system. This is the major component of the present model as depicted in Fig. 1. This models a system consisting from a flat plate solar collector, a stratified storage tank (either vertical or horizontal cylinder), and a check valve to prevent reverse flow, which employs water as the working fluid.

Flow in the loop is assumed to be steady state. The system is analysed by dividing the thermosyphon loop into a number of segments normal to the flow direction and applying Bernoulli's equation for incompressible flow to each segment.

The flow rate is obtained by numerical solution of the resulting set of equations. The stratification in the tank is modelled using TYPE 38 algebraic component, which is embodied in TYPE 45. The number of segments (nodes) in this model is not fixed, but depends on many factors, i.e. the simulation time step, the size of the collector, load flow rates, heat losses and auxiliary input (Fanney and Klein, 1983). In this model the simulation starts with a certain number of segments. As the hot water leaves the top of the collector and enters the storage tank from a certain point at the top, it mixes with water at this level if their temperatures are within 0.5 °C. If its temperature is lower than that at the top by more than 0.5°C it flows down and mixes with water of a segment where the temperature is within 0.5°C of it. In the case when the temperature of water entering the storage tank is higher than that at the top of the storage tank by more than 0.5°C, a new segment is created at the top, increasing the number of segments by one. When hot water is drawn to the load, the same case applies for cold water from the main entering the tank from the bottom, this water mixes with that at the bottom if their temperatures are within 0.5°C of each other, otherwise a new segment is created.

The system's design parameters and the input data required for the operation of TYPE 45 are outlined in Table 2 and Table 3 respectively which also list the actual values adopted for the thermosyphon solar water heater under investigation. It should be noted that the intercept and slope of the efficiency against (Tci-Ta)/IT curve (parameters 2 and 3 in Table 2) have been obtained from the performance test of the solar panel of the collector carried out by the Ministry of Commerce and Industry. The output information TYPE 45 can provide is shown in Table 4.

5. MODEL VALIDATION

Once the TRNSYS model of the thermosyphon solar water heater under investigation had been constructed the next step would be to simulate it with actual weather data. For this reason physical experiments for a number of consecutive days will be performed at the location where the solar heating system is installed. The weather parameters during experimentation will be monitored and their values will be used as input to TRNSYS. Furthermore the simulated performance obtained with TRNSYS and measured input data will be compared with the measured (experimental) performance. This model validation study is conducted with the purpose to determine the degree to which the TRNSYS model serves as a valid and representative model for the real thermosyphon solar water heater.

Table 2. System design parameters.

Parameter	Description	Value
Ac	Collector area (m^2)	2.71
$F_R(\tau\alpha)n$	Intercept of the efficiency vs (Tci-Ta)/I_T curve	0.792
F_RU_L	Negative of the slope of the efficiency vs. (Tci- Ta)/I_T curve (kJ/hr-m^2-°C)	23.994
Gtest	Mass flowrate per unit collector area for test conditions (kg/hr-m^2)	96
bo	Incidence angle modifier constant	0.1
β	Collector slope (degrees)	40
LU	for LU<1 collector pressure drop calculated internally	-1
NR	Number of parallel collector risers	12
dR	Riser diameter (m)	0.0135
dH	Header diameter (m)	0.026
H	Header length (m)	1.9
Nx	Number of collector nodes for thermal head calculations	3
Hc	Vertical distance between collector outlet and inlet (m)	0.78
Ho	Vertical distance between outlet of tank and inlet of collector (m)	0.78
di	Diameter of collector inlet pipe (m)	0.02
Li	Length of collector inlet pipe (m)	1.93
NB1	Number of right angle bends (or equivalent) in inlet pipe	2
Ui	Loss coefficient of collector inlet pipe plus insulation (kJ/hr-m^2-°C)	5.1
do	Diameter of collector outlet piping (m)	0.02
Lo	Length of collector outlet piping (m)	0.46
NB2	Number of right angle bends (or equivalent) in collector outlet piping	2
Uo	Loss coefficient of collector outlet pipe plus insulation (kJ/hr-m^2-°C)	5.1
Tank modes	1-Fixed inlet positions 2-Variable inlet positions	1
Vt	Tank volume (m^3)	0.15
Ht	Tank height (if vertical) or diameter (if horizontal) (m)	0.60
HR	Height of collector return to tank above bottom of tank (m)	0.29
Cp	Fluid specific heat (kJ/kg-°C)	4.19
ρs	Fluid density at standard conditions (kg/m^3)	1000
kw	Thermal conductivity of fluid in the tank (0 for no conduction) or effective thermal conductivity of fluid and walls	2.3
Tank Configur.	1-vertical cylinder 2-horizontal cylinder	2
UA	Overall UA value for tank (kJ/hr-°C)	17.9
ri	Ratio of insulation at the top and bottom of a horizontal cylindrical tank (=1 if tank is concentric with jacket)	1
TI	Initial temperature of preheat portion of tank (°C)	18
Qhe	Maximum rate of energy input by auxiliary heater (kJ/hr)	10800
Ha	Height of auxiliary heater above bottom of tank (m)	0.245
Hth	Height of thermostat above bottom of tank (m)	0.245
Tset	Set temperature (°C)	50
ΔTdb	Thermostat temperature dead band (°C)	1
(UA)f	Conductance of heat loss to flue (kJ/hr-°C)	0

Table 3. Input data.

Input	Description	Value
IT	Incident radiation (kJ/m²-hr)	16,6
I_H	Horizontal radiation (kJ/m²-hr)	16,4
Id	Horizontal diffuse radiation (Kj/m²-hr)	16,5
θ	Incidence angle (degrees)	16,9
P_g	Ground reflectance	0.3 (constant)
Ta	Ambient temperature (°C)	9,5
TL	Temperature of replacement fluid from load (°C)	17,1
M_L	Mass flowrate from load (kg/hr)	11,2
Tenv	Environmental temperature for losses from storage (°C)	9,5

Table 4. Output Information

Output	Description
1. Th	Temperature of hot fluid entering storage (°C)
2. Qu	Useful energy from collector (kJ/hr) (not including pipe losses)
3. TR	Temperature return to collector (°C)
4. mw	Flowrate to collector (kg/hr)
5. TD	Temperature of fluid delivered to load (°C)
6. mL	Flowrate to load (kg/hr)
7. Qenv	Storage losses (kJ/hr)
8. Qsup	Energy supplied to load (kJ/hr)
9. ΔE	Change in internal energy of storage since start of simulation (kJ)

5.1. Description of the Experimental Set-up

A typical thermosyphon solar water heating system installed in Nicosia was chosen to carry out the experiments.

Each experiment was started and finished by measuring the initial and end of day water temperature in the storage tank. In order to take into account the storage tank stratification effects the top and bottom water temperatures were measured with a thermometer and the mean of the two was considered as the mean storage tank temperature. To accomplish the above, the storage tank was modified by installing valves at its top and bottom points, and drawing a small quantity of water (about 1 litre) and measuring its temperature. Also each experiment was started by emptying the water tank and charging it with fresh tap water. Furthermore, the auxiliary heater was not activated during the experimentation and no water was drawn off from the system during daytime.

Solar insolation was measured by means of an Eppley pyranometer installed on a horizontal surface near the thermosyphon solar water heating system. This pyranometer had been compared with the Eppley group of reference standards. The accuracy of its measurements is estimated to be ±1 percent of the entire temperature range employed.

The ambient conditions were measured by the means of temperature sensors and wind velocity sensor (anemometer). During the experiments solar insolation, ambient temperature, and wind velocity were measured and recorded every ten minutes. This time interval was identical to the time interval employed in the study of Shitzer et al. (1979) as well as Braun and Fanney (1983).

5.2. Model Validation

The experiments were performed during December of 1998 through May 1999 for a total of 25 days. The number of consecutive days for each month that experiments were conducted are shown in Table 5.

This time span is more than what others have followed to reach to the same conclusions concerning the accuracy of the simulation programs.

Table 5 Number of consecutive days that experiments were conducted.

Year	Month	Number of consecutive days
1998	December	3
1999	January	4
	February	3
	March	5
	April	5
	May	5
	Total:	**25**

The weather data gathered namely; horizontal global radiation, ambient air temperature, and wind velocity, were used to modify a copy of the TMY file, which was subsequently used with TRNSYS model in order to predict the mean water storage temperature. For simplification of the validation process, no water was drawn off from the storage tank, and the electric element remained inactive during experimentation.

Table 6 tabulates a sample of the recorded data. The data refer to the average hourly values of the weather conditions for the 23rd of February. The actual (experimental) and predicted (modelled) initial and end of day storage water temperature is also shown in Table 6 for comparison. The temperature rise (ΔT) of the water in the storage tank is the parameter which is used for validation of the accuracy of the TRNSYS model. An attempt was made to have the actual initial storage tank temperature as close as possible to the modelled one to avoid possible errors.

A comparison of the water temperature rise between the actual and predicted results together with their percentage differences for all the days considered in the experiments are shown in Table 7. As can be seen the predicted results agree well with the actual values and the mean percentage difference between the two is within 4.68%, which is quite acceptable and reasonable.

Table 6 System performance and comparison of actual and model results (sample).

Time	Ambient temperature [°C]	Horizontal Global radiation [W/m2]	Direct radiation [W/m2]	Wind velocity [m/s]	Storage tank temperature (actual) [°C]	Storage tank temperature (modelled) [°C]
8.00	13.7	278.4	674.1	1	23.6	21.1
9.00	14.7	443.7	816.3	1.5		
10.00	16.1	603.3	860.7	1		
11.00	16.7	692.1	896.2	1.5		
12.00	17.3	673.3	905.1	1		
13.00	17.7	656.6	913.9	1		
14.00	17.6	612.2	940.6	1.5		
15.00	17.2	479.1	798.6	1		
16.00	16.9	292.8	674.4	1.5	49.7	48.0
			Daily temperature rise (ΔT):		26.1	26.9

From the results tabulated in Table 7 can be concluded that the model constructed for the thermosyphon solar water heating system is representative of the real system and can be used confidently to estimate the system's dynamic behaviour and long term integrated performance. Also it can be concluded that this modelling approach can be used for an in depth analysis of real systems and can assist in the efforts for improving a real system by optimising the parameters affecting its performance.

Table 7 Comparison of actual and modelled results and their percentage differences.

Test day	Actual data		Modelled data		Absolute % difference between actual and modelled water temp. rise values
	Initial tank temperature [°C]	Final tank temperature [°C]	Initial tank temperature [°C]	Final tank temperature [°C]	
Dec 20	26.1	43.7	27.2	44.4	2.27
Dec 21	30.2	48.5	27.2	46.5	5.46
Dec 22	29.3	44.8	23.7	42.5	21.29
Jan 15	27.4	49.0	26.2	47.5	1.39
Jan 16	28.5	48.7	27.7	48.5	2.78
Jan 17	24.5	42.1	23.9	41.8	1.70
Jan 18	25.2	42.4	24.5	42.0	1.74
Feb 21	27.0	49.5	27.3	50.2	1.78
Feb 22	26.4	54.2	19.3	49.2	7.55
Feb 23	23.6	49.7	21.1	48.0	3.07
Mar 12	25.6	55.2	26.2	56.4	2.03
Mar 13	26.7	57.4	26.1	56.9	0.33
Mar 14	24.4	56.8	23.1	56.0	1.54
Mar 15	25.0	54.4	24.6	53.2	2.72
Mar 16	26.7	56.5	24.1	57.2	11.07
Apr 10	28.1	67.2	26.3	62.4	7.67
Apr 11	27.3	67.8	25.9	64.2	5.43
Apr 12	31.4	66.7	28.4	66.1	6.37
Apr 13	30.1	64.4	27.5	65.6	9.97
Apr 14	29.6	65.4	28.1	63.5	1.11
May 16	25.7	64.2	25.0	62.1	3.64
May 17	29.1	61.7	30.4	61.9	3.37
May 18	31.4	63.6	30.1	60.4	5.90
May 19	26.4	60.7	26.1	59.6	2.33
May 20	30.3	67.4	30.0	65.4	4.58
			Mean percentage difference:		4.68

5.3. Possible Causes of the Differences Between Simulation and Actual Results

As can be seen from Table 7 in a few days the percentage difference between the actual and the modelled temperature difference is near or above 10%. The reason for this deviation may be due to weather conditions, which during those days were very unstable. This means that the mean hourly values used as input to the program may not be representative of the actual input to the system.

Other possible causes that have contributed to the deviation between the actual and model results are the following:

1. The measuring equipment may not be as accurate as it should be or as indicated by their manufacturers. Some of these, like the pyranometer, may need re-calibration.
2. Determining the mean storage tank temperature by measuring the temperature of the water at the top and bottom of the storage tank and taking the mean value may not represent the actual mean storage tank temperature due to the fact that the "thickness of each temperature layer" in the tank cannot be determined. In order to estimate more representatively the mean storage water temperature (taking into account the stratification effects) the cylinder should be modified by inserting a number of thermometers along its side at various heights. This is even more difficult in the case of horizontal storage tanks. However the horizontal storage tanks exhibit a very poor stratification which is their main disadvantage. This type of tank is used mainly in an attempt to reduce the height of the whole system.
3. The performance characteristic curve may not be as accurate as it should be. This is very important as the performance of the solar collector determines how much energy, from the quantity falling on the collector aperture, is intercepted.
4. Heat losses to the surroundings may be different from those calculated by TRNSYS program due to variation of the real insulation properties.

6. CONCLUSIONS

The objective of this study was to model a thermosyphon solar water heater and validate the model through simple experiments. The modelling was performed with TRNSYS program. The validation process revealed a good agreement between the model and experimental (actual) results with a mean percentage error of 4.68%. This means that the model constructed represents the real system and can be used confidently to estimate its dynamic behaviour and integrated performance. It can also be extracted that TRNSYS program in general is accurate enough and can be used with confidence to model solar systems.

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BIOCLIMATIC DESIGN FOR THE NEW UNIVERSITY OF CYPRUS CAMPUS 2nd COMPETITION: PHASE A, STUDENT HOUSING

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Abstract

The design for the new University of Cyprus campus is being developed in a series of six competitions, paralleling the six "phases" of construction. Awards are being made both to the best overall design, which then also determines the architectural firm responsible for that phase, as well as for the best bioclimatic design. This paper describes the first-prize winner in both categories for the second of this series of competitions, representing the first phase of student housing design. The author is the consultant of the bioclimatic design. The whole study was carried out as an integrated approach, taking into consideration a very wide range of design choices and parameters, with a conscious focus on bioclimatic design. There was an effort to combine traditional wisdom, new technology, function and comfort, cost, natural environment and microclimate, energy saving, client programme, and aesthetics. These were tailored to the particular requirements of the buildings. Energy-efficient design is used throughout, including careful and appropriate placement of insulation in relation to interior thermal mass. This is assisted by "smart-control" mechanical systems for heating and cooling. Daylighting is integral to the design, with energy-efficient supporting lighting systems. The designs also promote natural summer cooling ventilation, utilizing the prevailing summer wind direction as well as enhancing stack-effect ventilation.

1. INTRODUCTION

This design encompasses housing for 208 students. These are blocked into twelve individual buildings, consisting of four blocks of twelve rooms, four of twenty-four rooms, one of forty-eight rooms, and three houses with two for six persons and one for four, as well as a common space. This carries on the "village" scheme first established in Phase I.

The bioclimatic design is consciously integrated into the whole planning, siting and architecture of the scheme. There is an effort to combine traditional wisdom with new technology and aesthetics. In this context a range of parameters were considered, such as the natural environment, climate, microclimate, the building programme, economics, symbolisms and aesthetics.

The siting of the buildings and treatment of open spaces utilizes the natural topography and environmental features. Most of the existing trees are to be preserved to provide wind protection and to assist the other natural cooling features.

The buildings are oriented on East-West axes, to provide for favorable winter solar gain, summer shading, year-round daylighting and natural ventilation. All blocks of buildings feature fixed external passive shading devices. In addition, four of the blocks are beneath a fixed canopy shade, with slats spaced and angled to allow for winter sun exposure and summer sun protection, complementing the passive solar design of the structures. The designs also promote natural summer cooling ventilation, utilizing the prevailing summer wind direction as well as enhancing stack-effect ventilation. These are assisted by rock-bed pre-cooling in the buildings, and rock and screen evaporative cooling structures upwind from the buildings.

2. ZONING THE SITE

This portion of the University design is a natural continuation of the Central University buildings. It enters like a wedge of movement and social activities, connecting and interrelating the housing units with the surrounding open space.

The site is divided into four zones, outside to inside, which define and express different spatial qualities and functions:

- The Green Belt (zone):
  - Isolating zone from the public road
  - Acoustic insulation
  - Indirect optical boundary
  - Forming the natural microclimate
- Residential Zone

- Movement and Circulation Zones
- Zone of Open Space

The movement of the route through this portion of the campus is organized by the structure of the buildings, running through a two-way road, to all housing units. The site enters the buildings and the buildings to the site in a simultaneous, active intervention of the green to the building volume and vice versa.

3. THE MICROCLIMATE

The appropriate microclimate is formed by thoughtfully siting the buildings and landscaping the site and the open spaces. For such planning the requirements of the programme, the particularities of the buildings, the site limitations and its morphology, and the local climatic conditions, are all considered. In effect, the topography and generally the beneficial aspects of the surroundings are utilized as integral design elements.

The pedestrian circulation forms dynamic design elements in the site layout. These are routes on three levels. The ground level one is shaded by the first level route, which is shaded by the upper. The upper level is protected with planting above.

Figure 1. *Courtyard defined by circular wall with wetted rubble stone columns for summer evaporative cooling and enhancement of western breezes. In winter the courtyard becomes a pleasant sunny place, warmed by sun and mass.*

The main open space is formed centrally, connected with the building of common spaces and the semi-open route of circulation and parking. It is paved and acts like a large courtyard, sunny in winter and cool in summer. The uncovered paved surfaces offer pleasant sitting areas to enjoy the warmth of the winter sun. In the summer, open to the clear cold nocturnal sky, they cool by long wave radiation and moderate the heat of the hot days, around them.

Within it the open space, which is defined by a circular wall, is pleasant for both summer and winter. It is partly solid toward the northern side for wind protection and the remaining wall and columns are built out of loose rubble stones encased in metal mesh. This is shown in plan view in Fig. 1.

In the summer, recycled water trickles through the stones, providing coolness to the adjacent areas. The stone wall and columns are facing the western cool summer breezes so they enhance effectively the cooling of the open and semi-open sitting space. In the winter the stonework is not wetted so that it acts as a wall and columns for solar collection, storage and warmth of the space, which becomes a pleasant sunny courtyard.

Paving is also used as a measure against dampness, on the ground level, at the perimeter of the buildings, forming verandas for the ground level units. These paved surfaces are shaded in the summer, with the balconies above. In this way, possible glare and overheating resulting from reflection of the high summer sun are avoided.

Most of the existing vegetation is retained. The eucalyptus clusters are enhanced at the northern side with more trees for wind protection. At the east and west, tall Cypress trees allow the summer breezes through their bare lower trunk, whilst they intercept the low morning and afternoon sun in the summer with their compact vertical foliage.

Tree planting at other zones of the housing and open spaces defines site boundaries and courtyards in-between the buildings. It is used to reduce air temperature and to provide shading for the parking space, which is sunken at a lower level, to isolate it visually and acoustically.

4. THE BUILDINGS

The natural contours of the site are used to locate the buildings in an amphitheater configuration. They are stepping up from the south toward the north side, at calculated distances, achieving unobstructed solar access and wind protection from cold north winds for both the buildings and the courtyards. This is shown in Fig. 2, next page.

The buildings on the West Side of the plot, due to the natural contours, are raised at a higher level. The space between the ground and the underside of the buildings is filled with loose rubble stones, encased in metal wire. In the summer it is wetted with water, enhancing the cooling effect of the westerly summer breezes (Fig. 4). Openings in the ground floor insulated and waterproofed slab, channel coolness into the rooms. The free flow of air towards all directions and through the gaps between the stones, under the floor slabs, dissipates coolness in the surrounding areas. It also avoids dampness and creation of mold.

The water, which is used for the wetting of the stones, is collected in waterproofed metal trays and is recycled with the aid of a pump, for water conservation. The pumps are activated by an array of photovoltaic panels for solar energy utilization.

4.1 Shape, Mass, Orientation, Layout and Openings

In all buildings, the shape, the mass, the orientation, the layout and the openings have been designed to meet the conditions of bioclimatic architecture.

The elongated shape of the buildings, with an east-west axis, has a maximum deviation of 17 degrees from the south, allowing favorable solar orientation to all student units and most common living spaces in all buildings. The collection of solar heat in the winter reduces energy for mechanical heating.

The east and west ends do not receive significant solar radiation in winter while in the summer they receive high amounts of unwanted solar radiation. This explains the chosen elongated east-west configuration, with minimal east and west exposure. An orientation east of south exposes the units to more morning than afternoon sun and enables them to begin to heat earlier in the day (Fig. 2).

The sheltered spaces of balconies and verandas provide pleasant, private living spaces and an amenity

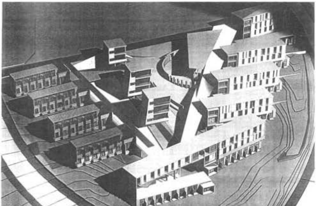

Figure 2: *A model of the buildings, showing the stepping up from south toward north, at calculated distances, to achieve unobstructed solar access, as well as wind protection from the north in winter, for both the buildings and courtyards.*

in themselves, as well as preconditioning the exterior climate to make indoor comfort control more easily achieved. In winter they form warm sunny pockets. These, with their warm areas immediately outside the units expand the length of the usefulness of outdoor living areas, but the heating effect will provide additional benefit by creating a warmer climate outside the rooms, thereby reducing winter heat loss. In the summer, they shade the walls, the openings and surrounding ground and outdoor floor surfaces. This helps to keep the temperature of the outdoor air low, making natural ventilation more suitable and minimizing conductive heat gain through the walls.

The large south glazing is the source of solar gain in winter when the sun path is low and its warmth welcome. Unobstructed solar access is provided to all living units from sunrise to sunset, from the beginning of October to mid March. (This is shown in Fig. 3, on the next page.) The sun, in December 21, has a maximum altitude of 35 degrees and azimuth of 130 degrees.

During the summer, appropriately proportioned overhangs and vertical sidewalls provide solar protection. The horizontal overhangs provide solar protection from the high summer sun, from mid April until the end of August, at least from 11.00 to 3.30. The sidewalls intercept the low morning and afternoon unwanted sun for the rest of the times, during those months. Additional solar protection for the buildings on the East Side is provided by vertical external perforated sliding metal screens. For the buildings on the West Side, solar control is provided by an elevated horizontal shading lattice made out of metal slats at calculated angles for solar transmission in winter and protection in summer. The slats become denser above the top open balconies. Both types of solar protection allow airflow through them, to avoid overheating and encourage ventilation. (This is shown in Fig. 4.)

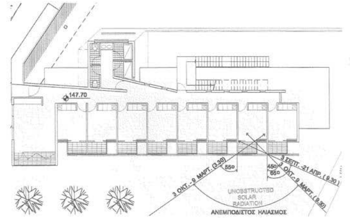

Fig. 3. The elongated shape of the structures, with an east-west long axis, allows favorable solar orientation to all student living units and common spaces, in all buildings. Shown is the unobstructed solar access, sunrise to sunset, from the beginning of October to mid-March.

4.2 Wind Protection - Limiting Heat Losses

The common bathrooms and toilets on the northern side—which is the windward side of the structures—and the covered corridors extending as entryways to the rooms, collectively act as a buffer zone, providing wind protection and restricting heat losses. The corridors are fully partitioned from the heated zones. These decrease the temperature gradient across the partition between the heated living units and the unheated corridors and thus retard the rate of heat loss.

4.3 *Ventilation*

The northern corridors of the housing units have openings to the west and east sides as well as on the top of the walls. The prevailing summer breezes, which are mainly from the west but occasionally northwest or southeast, enter the corridors within 30 to 45 degrees of the opening direction. These are the best conditions for the provision of cross ventilation, and they are favorable for the circulation of airflow in the corridors and into the rooms.

In addition, the range of the sizes and location of the opening (entrance doors, north and south top windows, balcony doors) offers flexibility. The occupants can regulate the opening part and in effect the potential for most beneficial ventilation according to the direction of breezes and the desired flow of air.

The overhangs above the corridors and balconies direct the cooling breezes towards the opening. Through the top windows the air flows towards the ceiling, which is concrete and therefore has thermal storage mass, so that it retains the coolness of the night. In addition, the top openings offer safety as well as visual privacy. The ceiling fan (a program requirement) circulates the airflow, which otherwise would tend to stratify, distributing it to the entire room. (This is shown in Fig. 4, on the next page.)

4.4 *Daylighting*

The linear layout of the building plans in a one room depth offers the potential for natural lighting from the two opposite sides, which is ideal for uniform visually comfortable lighting distribution without glare (again Fig. 4). Furthermore the top windows in combination with the glazed doors achieve a high daylighting factor, so it is possible for the occupants to regulate the intensity of the daylight according to their needs or desires.

The north top window openings offer uniform natural lighting, free of glare. Glare prevention is also offered by the use of overhangs, side fins and the overhead horizontal slatted shading device suspended over the west housing units. Furthermore, reduction of glare is provided by the sliding, perforated screens, which reduce the brightness of the glazed openings on the east housing units.

The reduction of extreme contrast is achieved with the use of soft light colors on the walls and ceilings, which give better distribution of the lighting.

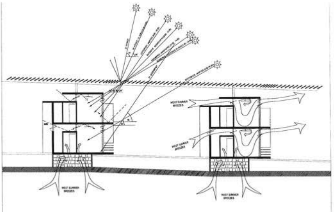

Fig. 4. Section views showing, in winter, the sun penetration in the center of the day through the properly angled canopy slats. In summer, direct sun penetration is prevented by the slat angle and spacing. The narrow shape and placement of openings promote natural ventilation. Evaporative cooling from the underfloor wetted rubble stones provides additional summer comfort.

5. CONSTRUCTION

All the buildings are reinforced concrete frame structures with infill panels of concrete blocks, which are locally manufactured. This type of massive construction, in addition to the concrete floor and roof slabs, offers time lag as well as thermal storage. This is of particular significance for the Cyprus climatic conditions, due to the characteristic of large diurnal fluctuations (5 to 25 degrees Celsius) and the potential inherent in mass for large solar contribution in winter and cooling in the night.

The walls are insulated externally with rigid extruded polystyrene and rendered with plaster on plastic mesh painted white for sun reflection.

The concrete floor slabs are finished with screed and mosaic tiles, enhancing their thermal capacity. The concrete roof slabs are topped with lightweight concrete screed forming slopes for water collection, waterproofing membrane and insulation to intercept the summer solar radiation. A protection layer of white chipping acts as a reflecting surface, necessary for the reflection of the almost vertical summer sunrays.

Double-glazing with low emissivity coating is used on all windows for limiting the heat losses in winter and heat gains in the summer.

6. CONCLUSION

All the buildings are sited, planned, designed and detailed to minimize the mechanical heating and cooling requirements.

The landscaping, the amphitheatrical siting of the buildings opening with large glazing to the south, and the use of appropriate shading devices ranging from overhangs, side walls, perforated screens and suspended metal lattice, ensure unobstructed solar access, wind protection in winter, exposure to breezes and solar protection in the summer.

The building plan with the living spaces facing south provide solar-oriented interior zones for maximum solar heat gain.

The corridors stretching at the back of the buildings and the low-use spaces of bathrooms and cupboards act as climatic buffers zones, shielding the entryways of the rooms from the cold northern winds, while in the summer they channel the cool summer breezes.

The openings are located for winter solar collection, cross ventilation and uniform natural lighting free from glare.

Special features such as the enclosing stone wall of the common courtyard, and the rubble stones under the west rows of buildings wetted in the summer for evaporative cooling and kept dry in winter for solar gains, enhance the bioclimatic performance of the buildings.

This award winning concept continues to demonstrate that designs for comfort, convenience and utility, within tight budgets, can still attain low energy consumption and low greenhouse gas emissions. The key to this, as it was in the first winning competition, is the appropriate use of bioclimatic design principles in a holistic, integrated approach. These first two winning design phases (out of six) should now assure that the finished complete campus design will carry through with these principles. If it does, it will certainly be worthy of international architectural attention.

REFERENCES

Aitken, D.W., Kyprianou, A., 1999, Bioclimatic Designs for the New University of Cyprus Campus, 1st Competition: Facilities for Science and Technology, this Proceedings.