Commission of the European Communities

energy

Extended abstracts of final reports in the field of solar energy applications to dwellings

Report

EUR 7977 EN

Commission of the European Communities

Extended abstracts of final reports in the field of solar energy applications to dwellings

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MISCELLANEOUS

FOREWORD

"SOLAR ENERGY APPLICATIONS TO DWELLINGS", PROJECT A, IS ONE OF THE EIGHT TASKS WHICH FORM TOGETHER THE SOLAR ENERGY R+D PROGRAMME OF THE DIRECTORATE GENERAL XII, FOR SCIENCE, RESEARCH AND DEVELOPMENT OF THE COMMISSION OF THE EUROPEAN COMMUNITIES.

IT INCLUDES TWO TYPES OF ACTIONS :

1 - THE "CONCERTED ACTIONS", WHICH ARE EXECUTED WITH A COMMON PROGRAMME IN DIFFERENT COUNTRIES, AT THE SAME TIME.
THESE ACTIONS ARE DEALING WITH :
* MODELLING OF SOLAR HEATING AND DOMESTIC HOT WATER SYSTEMS
* VALIDATION OF THESE MODELS WITH DATA FROM SOLAR PILOT TEST FACILITIES
* PERFORMANCE MONITORING OF SOLAR HOUSES
* COLLECTOR TESTING
* PASSIVE SYSTEMS
* MODELLING OF PASSIVE SYSTEMS.

2 - INDIVIDUAL RESEARCH PROGRAMMES CARRIED OUT WITHIN THE FRAME OF CONTRACTS WITH RESEARCH INSTITUTES OR PRIVATE COMPANIES, AND DEALING WITH SOLAR HEAT STORAGE AND SOLAR COOLING MAINLY.

THE PRESENT DOCUMENT CONTAINS THE EXTENDED ABSTRACTS OF THE FINAL REPORTS OF THE RESEARCH WORK, AS THEY BECAME AVAILABLE IN THE LAST TWO YEARS.

TITLE : DEVELOPMENT OF A THERMAL STORAGE SYSTEM BASED ON ENCAPSULATED P.C. MATERIALS

CONTRACT NR : 508-78-4-ESN

ORGANIZATION : TECHNISCH PHYSISCHE DIENST TNO-TH
STIELTJESWEG 1
POSTBUS 155
NL - 2600 AD DELFT

PROJECT HEAD : E. VAN GALEN

INTRODUCTION

DIFFERENT FORMS OF SOLAR THERMAL STORAGE ARE GENERALLY DISCUSSED LEADING TO LATENT HEAT STORES FOR SPACE HEATING. THE SYSTEM DESCRIBED HERE WAS A PHASE CHANGE MATERIAL IN A STABILIZING COLLOIDAL POLYMER MATRIX.
RESULTS OF PREVIOUS CONTRACTS ARE INCORPORATED HERE.

SOLAR HEATING INSTALLATIONS

AN OUTLINE DESCRIPTION IS PRESENTED OF A SOLAR INSTALLATION SHOWING ITS OPERATION AND THE FUNCTION OF STORAGE.
A COMPUTER PROGRAM WAS DEVELOPED TO CALCULATE HOUSE HEATING LOADS FROM WEATHER DATA, AND IS DESCRIBED HERE. A REAL SOLAR HOUSE WHICH IS WELL MONITORED WAS USED AS A REFERENCE TO CARRY OUT PRELIMINARY CALCULATIONS ON THE SIZING OF THE STORAGE SYSTEM AND COMPONENTS, USING A SIMPLIFIED STORAGE MODEL WHICH IGNORES SUPER COOLING AND STRATIFICATION.

IT WAS FOUND THAT A TRANSITION TEMPERATURE BETWEEN 40 AND 50 "C IS REQUIRED IN PRACTICE. TWO SETS OF CLIMATIC DATA, FOR THE NETHERLANDS AND SOUTHERN FRANCE HIGHLIGHTED THE IMPORTANCE OF ATTENTION TO DESIGN OF PRIMARY CIRCUITS IN NORTHERN CLIMATES AND TO SECONDARY CIRCUITS IN SOUTHERN CLIMATES.

DESCRIPTION OF TEST PROCEDURE

A TEST PROCEDURE FOR THE STORAGE SYSTEM WAS DEVELOPED BY MODIFYING THE NBS METHOD TO PROVIDE TWO RATES OF HEAT LOSS, THREE RATES OF CHARGE AND DISCHARGE. THE THERMAL STORAGE CAPACITY OF THE SYSTEM MUST FIRST BE KNOWN BEFORE MEASURING THE HEAT LOSS RATE AND CHARGING AND DISCHARGING RATES AS SPECIFIED.

THE INTERPRETATION OF TEST RESULTS IS DISCUSSED IN RELATION TO

CORRESPONDING RESULTS FROM THE NBS TEST METHOD.
THE PERFORMANCE OF A THERMAL STORE CAN BEST BE TESTED UNDER VARYING BOUNDARY CONDITIONS SUCH AS OCCUR IN PRACTICE, AND THIS REQUIRES A SPECIAL TEST CIRCUIT.

DESIGN OF A TEST CIRCUIT

THE DESIGN AND CHOICE OF HEAT EXCHANGERS FOR THE MODIFIED TEST LOOP ARE DESCRIBED IN SOME DETAIL.
THE TEST LOOP MUST BE SUITABLE FOR THE NBS TEST AND FOR THE REAL TEST UNDER VARYING BOUNDARY CONDITIONS. THE NBS TEST REQUIRES TWO LOOPS, ONE FOR CHARGING AT CONSTANT INLET TEMPERATURE AND ONE FOR DISCHARGING LIKEWISE.

THE SIMULATION TESTS CAN USE THE SAME LOOPS BUT UNDER DIFFERENT CONTROL WHICH RELATES CHARGE AND DISCHARGE TEMPERATURES TO WEATHER CONDITIONS, BY MEANS OF A COMPLETE SYSTEM SIMULATION PROGRAM WHICH DEALS ALSO WITH THE HOUSE HEATING LOAD.

SETPOINTS ARE RE-CALCULATED EVERY FIVE MINUTES, USING A MICRO-PROCESSOR AND DATA LOGGER ASSEMBLY. THE PERFORMANCE OF A STORE IS THEN COMPARED BY COMPUTER SIMULATION TO THAT OF A SIMPLE NON-STRATIFIED WATER STORE. THE MICRO-PROCESSOR IS DESCRIBED.

SELECTION OF PHASE CHANGE MATERIALS

CRITERIA FOR SELECTION OF A PHASE CHANGE MATERIAL (PCM) ARE GIVEN, AND ARE FOUND TO BE BEST SATISFIED BY INORGANIC OR ORGANIC SALT HYDRATES. BASIC THERMAL PROPERTIES WERE MEASURED FOR SIX LIKELY CANDIDATES, CONTAINING NECESSARY ADDITIVES, AND ARE REPORTED.

A SODIUM PHOSPHATE DODECA HYDRATE WAS EVENTUALLY CHOSEN FOR THE FIRST PROTOTYPE. THE SECOND PROTOTYPE EMPLOYED A PCM WHICH HAD

BETTER INTRINSIC PROPERTIES BUT REQUIRED NUCLEATING AGENTS, OR AN AUTO-NUCLEATING ZONE KEPT PERMANENTLY COLD. A CELLULOSE DERIVATIVE WAS USED AS A STABILIZING MATRIX.
THERNAL STABILITY WAS NOT QUITE PERFECT.

PERFORMANCE OF PROTOTYPES 1 AND 2

PROTOTYPES 1 AND 2 WERE TESTED IN THE SIMULATION LOOP FOR ONE-WEEK PERIODS AND USING THE NBS PROCEDURE. DETAILS OF THE TEST SET UP ARE GIVEN, AND RESULTS ARE PRESENTED.
SHORT CIRCUITING FOUND TO BE POSSIBLE AND BENEFICIAL, WHEREIN HEAT FROM THE COLLECTORS PASSED STRAIGHT TO THE EMITTERS.
MEASURED RESULTS WILL BE COMPARED WITH CALCULATED VALUES USING A MATHEMATICAL FORMULATION OF THE SOLIDIFICATION FRONT.

THESE PRELIMINARY TESTS SHOW THAT AGEING PROBLEMS HAVE NOT BEEN SOLVED YET BUT THAT A VOLUME REDUCTION BY A FACTOR OF TWO IS POSSIBLE COMPARED TO A SIMPLE WATER STORE.

TITLE : HEAT STORAGE USING LATENT HEAT OF FUSION OF A SUBSTANCE ADSORBED ON A POROUS MATERIAL

CONTRACT NR : 115-77-ESF & ESA-S-014-F

ORGANIZATION : SOCIETE NATIONALE ELF AQUITAINE
RUE NELATON 7
F - 75015 PARIS

PROJECT HEAD : M. RONC

PUBLISHED AS MICROFICHE REPORT EUR 7703 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE OBJECTIVE OF THE PRESENT WORK IS TO SHOW THE FEASIBILITY AND ADVANTAGES OF A NEW AND ORIGINAL STORAGE PROCESS, USING THE LATENT HEAT OF FUSION OF A MATERIAL (PARAFFINE) ADSORBED ON POROUS PARTICLES (ACTIVATED CARBON).
THE AIM IS THEN TO MODELIZE THE STORAGE SYSTEM IN ORDER TO UNDERSTAND ITS THERMAL BEHAVIOUR, PREDICT ITS PERFORMANCES AND OPTIMIZE THE DESIGN AND OPERATING PARAMETERS.

SELECTION OF MATERIALS AND FIRST TRIALS

PARAFFINE 50/52 "TOTAL" HAS BEEN SELECTED AS THE PHASE CHANGE MATERIAL. DIFFERENT ADSORBENT MATERIALS HAVE BEEN TESTED, LEADING TO THE CHOICE OF "CECA ACTICARBON BGP".
ALTHOUGH WATER AND AIR COULD BE USED AS A HEAT TRANSFER MEDIUM, WATER HAS BEEN RETAINED FOR PRACTICAL REASONS.

A METAL TANK CANNOT BE USED AS STORAGE VESSEL, BECAUSE IT WOULD CAUSE AXIAL HEAT FLUXES ; THAT IS THE REASON WHY A PLASTIC MATERIAL HAS BEEN CHOSEN.

THE IMPREGNATION METHOD IS DESCRIBED AND THE RESULTS OF SMALL SCALE TESTS ARE PRESENTED.
IT IS FOUND THAT AN EXCESS OF PARAFFINE ON THE PARTICLES MAY CAUSE STICKING AND HENCE PREVENT GOOD OPERATION CONDITIONS.
FURTHERMORE, A LOSS OF PARAFFINE IS OBSERVED AFTER A FEW CYCLES OF CHARGE AND DISCHARGE.

STUDY OF A MODEL WITHOUT FUSION

AN ANALYTICAL STUDY IS PRESENTED, WHICH GIVES INFORMATION ON THE FLOW PATTERNS AND TEMPERATURE DISTRIBUTIONS. THIS THEORETICAL STUDY IS THEN COMPARED WITH THE RESULTS OF EXPERIMENTAL

TESTS, IN WHICH THE STORAGE MEDIUM IS MADE OF GLASS SPHERES OF 4 TO 10 mm DIAMETER.

STUDY WITH PHASE CHANGE

THE STORAGE TANK HAS BEEN FILLED WITH ACTIVATED CARBON IMPREGNATED WITH PARAFFINE, AND THE TEMPERATURE DISTRIBUTIONS HAVE BEEN MEASURED DURING SEVERAL CYCLES OF CHARGE AND DISCHARGE. DIFFERENT APPROACHES TO THE BEHAVIOUR OF THE SYSTEM ARE THEN DESCRIBED, TRYING TO OBTAIN A CORRECT SIMULATION MODEL.
THE DISCREPANCIES BETWEEN THE PREDICTED FIGURES AND THE MEASUREMENTS ARE EXPLAINED PHYSICALLY.

MECHANISM OF IMPREGNATION

THE MECHANISM OF IMPREGNATION OF THE PARAFFINE IS INVESTIGATED FROM A PHYSICAL AND CHEMICAL POINT OF VIEW. IT IS FOUND THAT THE MICROSTRUCTURE OF THE CARBON PARTICLES IS OF PRIMARY IMPORTANCE IN THIS MECHANISM AND CONDITIONS THE FINAL CHARACTERISTICS AND STABILITY OF THE IMPREGNATED MATRIX.

IT IS ALSO OBSERVED THAT A GOOD STABILITY CANNOT BE ACHIEVED WITHOUT DECREASING THE QUANTITY OF PARAFFINE THAT TAKES PART IN THE FUSION PROCESS, SO THAT THE EQUIVALENT HEAT OF FUSION DECREASE ASWELL.

CONCLUSIONS

IT HAS BEEN DEMONSTRATED THAT THE NEW STORAGE SYSTEM CAN BE SATISFACTORILY MODELLIZED. FROM A PRACTICAL POINT OF VIEW, AN EFFICIENT OPERATION HAS NOT BEEN REACHED.
FURTHER INVESTIGATIONS ON ADSORBING MATERIALS HAVE TO BE DONE AND SHOULD LEAD TO A BETTER STABILITY OF THE IMPREGNATED MATRIX.

TITLE : DEVELOPMENT OF A THERMAL STORAGE SYSTEM
BASED ON THE HEAT OF ADSORPTION
IN HYGROSCOPIC MATERIALS

CONTRACT NR : 518-78-1-ESN

ORGANIZATION : TECHNISCH PHYSISCHE DIENST TNO-TH
POSTBUS 155
NL - 2600 AD DELFT

PROJECT HEAD : J.K.M. VERDONSCHOT - C. DEN OUDEN

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HEAT STORAGE IN AIR BASED SOLAR HEATING SYSTEMS

IT IS POSSIBLE TO STORE HEAT BY DRYING AN HYGROSCOPIC MATERIAL, AT LOW TEMPERATURE LEVEL. AT DISCHARGE, THE WATER CONTAINED IN THE COLD AIR IS ADSORBED, WHICH CAUSES A LIBERATION OF HEAT.

PROPERTIES OF ADSORBENTS

THE MOST IMPORTANT PHYSICAL PROPERTIES OF THE FOLLOWING ADSORBENTS HAVE BEEN MEASURED :

* SILICAGEL
* SORBEAD-R
* MOLECULAR SIEVES.
* ACTIVATED ALUMINA
* SORBEAD-W

A HIGH STORED ENERGY DENSITY IS OBTAINED BY THE MATERIALS HAVING SIMULTANEOUSLY A HIGH HEAT OF ADSORPTION AND A HIGH WATER ADSORBING CAPACITY AT A GIVEN ABSOLUTE HUMIDITY AND TEMPERATURE RANGE.

THE AGEING OF THE ADSORBENT HAS BEEN CONSIDERED. AS A MATTER OF FACT, IT WAS FOUND THAT THE MAXIMUM WATER ADSORBING CAPACITY MAY DECREASE BY 10 - 20 % AFTER 400 CYCLES OF CHARGE/DISCHARGE.

COMPUTER MODELLING OF SOLAR HEATING SYSTEMS USING AN ADSORBENT AS HEAT STORAGE MEDIUM

A FIRST MODEL WAS SET UP TO DESCRIBE THE BEHAVIOUR OF A STORAGE SYSTEM EXPOSED TO A STEP CHANGE OF THE INLET AIR TEMPERATURE AND HUMIDITY. THE CHANGE OF PARAMETERS IN AXIAL DIRECTION OF THE VESSEL HAS BEEN TAKEN INTO ACCOUNT BY DIVIDING THE STORAGE INTO SUCCESSIVE SEGMENTS.

THE STORAGE MODEL HAS THEN BEEN CONSIDERED AS A PART OF A SOLAR HEATING SYSTEM, IN ORDER TO SIMULATE THE WHOLE DYNAMIC PROCESS,

I.E. CHARGING AND DISCHARGING TIMES AND TEMPERATURE CHANGES, AS FUNCTIONS OF SUPPLY AND DEMAND OF HEAT.

DIFFERENT INSTALLATION CONFIGURATIONS HAVE BEEN COUPLED WITH THE STORAGE SYSTEM IN ORDER TO CONCLUDE FOR THE MOST PROMISING. AN IMPROVED HEATING SYSTEM (SEE FIGURE PAGE 14) HAS BEEN STUDIED BY USING A COMPUTER MODEL WHICH CAN OPTIMIZE THE DESIGN AND WORKING PARAMETERS.

AS WAS EXPECTED, SORBEAD-R ADSORBENT GIVES THE HIGHEST CONTRIBUTION TO THE TOTAL HEAT DEMAND.

COMPARED WITH A ROCK BED STORAGE SYSTEM, IT CAN BE SEEN THAT AN ADSORBENT STORAGE OF 1 m3 GIVES THE SAME SOLAR CONTRIBUTION AS A ROCK BED STORAGE OF 6 m3.

ON THE OTHER HAND, A ROCK BED STORAGE OF 1 m3 ONLY GIVES 3 % LESS SOLAR CONTRIBUTION THAN THE ADSORBENT STORAGE OF THE SAME VOLUME.

EXPERIMENTAL INVESTIGATIONS

A HALF CUBIC METER STORAGE VESSEL HAS BEEN PLACED IN A TEST CIRCUIT, IN ORDER TO STUDY ITS OPERATION UNDER SIMULATED REAL CONDITIONS.

ALTHOUGH THE SHAPE OF TEMPERATURE AND HUMIDITY PROFILES ARE SIMILAR TO THE CALCULATED ONES, THE MEASUREMENTS OF TIME RESPONSES APPEAR TO BE LESS OPTIMIST THAN PREDICTED.
THE ORIGIN OF THIS DISCREPANCY LIES IN THE NON-UNIFORMITY OF TEMPERATURE IN THE VESSEL, AND IN A SIGNIFICANT RESISTANCE AGAINST HUMIDITY TRANSPORT INSIDE SORBEAD PARTICLES, WHICH ACTUALLY CANNOT BE KNOWN.

AS A MATTER OF FACT, IT HAS BEEN OBSERVED THAT THE RESPONSE

TIME AGREEMENT WITH PREDICTED VALUES DEPENDS ON AIR HUMIDITY.

THE PRESSURE DIFFERENCE OVER THE STORAGE VESSEL SHOWS A GOOD AGREEMENT WITH THE CALCULATIONS. FOR SMALL LENGTH/DIAMETER RATIOS, THIS PRESSURE DROP HAS NO SIGNIFICANT IMPORTANCE WITH RESPECT TO THE VENTILATION SYSTEM.

CONCLUSION

CONCLUSIONS ARISING FROM THE COMPARISON BETWEEN A ROCK BED AND ADSORBENT STORAGE HAVE ALREADY BEEN MENTIONED.

THE USE OF A HEAT STORAGE IMPROVES THE ENERGY SAVING WITH 5 - 7 % OF THE TOTAL HEAT DEMAND.
THEREFORE, THE STORAGE SYSTEM DESIGN HAS TO BE VERY SIMPLE, OTHERWISE NOT ECONOMICAL.

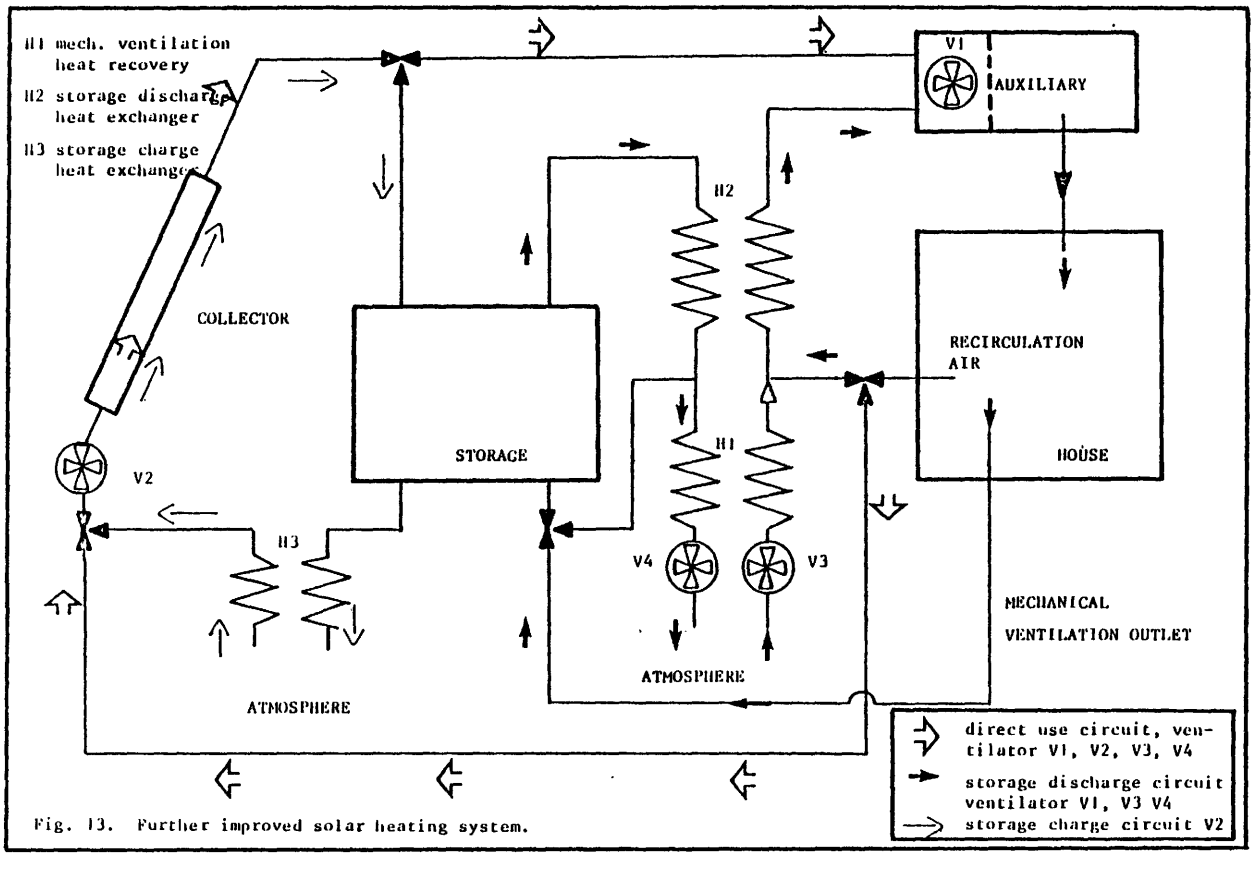

Fig. 13. Further improved solar heating system.

TITLE : OPTIMIZATION OF HEAT STORAGE SYSTEMS USING SILICAGELS

CONTRACT NR : 519-79-5-ESB

ORGANIZATION : FACULTE POLYTECHNIQUE DE MONS
RUE DE HOUDAIN 9
B - 7000 MONS

PROJECT HEAD : J. BOUGARD

PUBLISHED AS MICROFICHE REPORT EUR 7647 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE PRESENT RESEARCH FOLLOWS A PREVIOUS WORK UNDERTAKEN UNDER CEC CONTRACT NR 116-76-ESB, DURING WHICH THE STORAGE OF ENERGY WITH ADSORBENT MATERIALS HAS BEEN INVESTIGATED.

THE STORAGE UNIT IS NOW CONSIDERED AS A PART OF A COMPLETE SOLAR SYSTEM, AND CONSIDERATION IS GIVEN TO THE REDUCTION OF COMPUTATION TIME OF THE STORAGE MODELLING PROGRAMME.

COMPUTER SIMULATION AND EXPERIMENTAL RESULTS

THE NEW COMPUTER PROGRAMME IS BASED UPON THE FINITE DIFFERENCES METHOD. TAKING ITS SIMPLICITY INTO ACCOUNT, A GOOD AGREEMENT IS FOUND WITH EXPERIMENTS, CARRIED OUT WITH SILICAGEL "KC-TROCKENPERLEN BLAU".

STUDY OF SEVERAL HEATING SYSTEMS USING SILICAGEL STORAGE

THE HOT AIR SUPPLIED BY THE STORAGE SYSTEM IS TOO DRY WITH REGARD TO COMFORT CONDITIONS.
THREE SOLUTIONS HAVE BEEN STUDIED TO OVERCOME THIS SITUATION :

* MIXING THE HOT DRY AIR WITH TEPID HUMID AIR FROM A SATURATOR;
* HEATING THE OUTSIDE AIR WITH THE HOT DRY ONE IN A HEAT HEAT EXCHANGER;
* HEATING WATER INSTEAD OF AIR IN AN AIR/WATER HEAT EXCHANGER.

THE STORAGE IS SUPPOSED TO BE USED IN A TYPICAL SOLAR HEATED DWELLING PLACED UNDER BELGIAN METEOROLOGICAL CONDITIONS.
THE THREE SOLUTIONS MAKE USE OF A SATURATOR.

THE FIRST SOLUTION IS PROVEN TO BE THE MOST INTERESTING, ALTHOUGH IT REQUIRES AN ADDITIONAL HEAT SUPPLY DURING THE HEATING PERIOD, FOR THE ADSORBENT REGENERATION.
MOREOVER, THE REQUIRED AIR CONDITIONS ARE ACHIEVED WITHOUT UTILIZING THE ENTIRE STORAGE CAPACITY, BECAUSE HUMIDITY IS NOT HIGH ENOUGH TO ALLOW A SUFFICIENT RISE OF TEMPERATURE IN THE SILICAGEL COLUMN.

THE NEED FOR AN AIR TO AIR HEAT EXCHANGER MAKES THE SECOND PROPOSITION UNACCEPTABLE FROM AN ECONOMIC VIEWPOINT.
THE LOW EFFICIENCY OF SUCH EXCHANGERS, ASSOCIATED WITH THE FACT THAT THE STORAGE CAPACITY CANNOT BE USED COMPLETELY, MAKE THE CONFIGURATION UNFAVOURABLE.

THE LAST POSSIBILITY MAKES USE OF A WATER SPACE HEATING SYSTEM. THIS SOLUTION CAN REACH ITS OPTIMUM, BUT THE HEAT EXCHANGER PROVIDES ONLY TEPID WATER, AND THE SATURATOR CAUSES A HIGH ENERGY LOSS.

SILICAGEL PROPERTIES

SILICAGEL PROPERTIES ARE COMPARED BY WAY OF THEIR HEAT STORAGE CAPACITY. A LARGE DISCREPANCY HAVE BEEN FOUND BETWEEN THE COMMERCIALY AVAILABLE MATERIALS, SO THAT A FURTHER STUDY OF THEIR MICROSCOPIC CHARACTERISTICS HAS BEEN CARRIED OUT.

CONCLUSION

IT SHOULD BE NOTICED THAT THE THIRD SOLUTION PROPOSED ABOVE, WHICH IS RATHER ATTRACTIVE REGARDING ITS COMPACTNESS, HAS NOT BEEN SIMULATED VERY ACCURATELY. AS A MATTER OF FACT, THE HEAT EXCHANGE PROCESSES ARE OF COMPLICATED NATURE AND THE MODEL COULD NOT BE VALID IN THAT CASE.

THE BEST AND SIMPLEST WAY TO OVERCOME AIR DRYNESS WOULD CONSIST IN MIXING THE HOT DRY AIR WITH TEPID AIR COMING FROM THE SATURATOR.

CONSIDERING THE HIGH COST OF SILICAGELS, THE SYSTEMS EXAMINED IN THE PRESENT WORK SOULD USE RELATIVELY LOW STORAGE VOLUMES.

A 7-DAYS STORAGE TIME CAN BE ACHIEVED BY THE USE OF A 1 m3 VESSEL, OPERATING EFFICIENTLY DURING SPRING OR AUTUMN.

TITLE : DEVELOPMENT OF A PEBBLE BED HEAT STORAGE

CONTRACT NR : 649-78-7-ESF

ORGANIZATION : SOCIETE BERTIN
B.P. 3
F - 78370 PLAISIR

PROJECT HEAD : R. GROSSIN

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AIM OF THE RESEARCH

THE RESEARCH UNDERTAKEN IN THIS CONTRACT WAS AIMED AT A PHYSICAL AND NUMERICAL STUDY OF A PEBBLE BED SYSTEM ASSOCIATED WITH AIR SOLAR COLLECTORS, AND AT THE DESIGN, MANUFACTURING AND TESTING OF A FULL-SCALE PEBBLE STORAGE.

CHARACTERIZATION OF THE SYSTEM

A PEBBLE BED CAN BE USED TO STORE HEAT DURING THE DAY WHILE AVOIDING OVERHEATING IN THE HEATED DWELLING.

THE VENTILATION AIR FLOWS THROUGH THE PEBBLE BED ALWAYS IN THE SAME DIRECTION, ALTERNATIVELY BEING HEATED AND COOLED BY THE SOLID MATRIX, SO THAT THE HEAT STORAGE CAN BE CONSIDERED AS A PHASE SHIFTER.

THE SYSTEM IS CHARACTERIZED BY TWO QUANTITIES :

* THE TIME CONSTANT (TC), RATIO OF THE MATRIX SPECIFIC HEAT TO THAT OF THE FLOWING AIR ;
* THE NUMBER OF TRANSFER UNITS (NTU), RATIO OF THE OVERALL HEAT TRANSFER COEFFICIENT TO THE SPECIFIC HEAT OF THE FLOWING AIR.

NUMERICAL CALCULATIONS

THE THERMAL RESPONSE OF THE STORAGE SYSTEM HAS BEEN COMPUTED FOR A UNIT STEP CHANGE OR A PERIODIC VARIATION OF AIR INLET TEMPERATURE.

HIGH FREQUENCY VARIATIONS ARE FOUND TO BE RAPIDLY DAMPED.
IN A PERIODIC SIGNAL, ONLY THE FUNDAMENTAL TERM HAS TO BE CONSIDERED. IN THE PRESENT CASE, THE PERIOD OF THIS TERM IS 1 DAY.

WHEN HIGH VALUES OF THE NTU ARE CONSIDERED, THE STORAGE DELAYS THE HEAT INPUT BY A TIME EQUAL TO TC AND THUS ACTS AS A PHASE SHIFTER. ASSUMING A TIME STORAGE TIME CONSTANT RANGING FROM SEVERAL HOURS TO HALF OF A DAY, THIS BEHAVIOUR IS OBSERVED IF NTU IS GREATER THAN 25.

EXPERIMENTS WITH A SMALL SCALE STORAGE

A SMALL SCALE PEBBLE BED STORAGE (.4 X .4 X 1 m3) HAS BEEN TESTED. THE RESULTS SHOWED A GOOD AGREEMENT WITH THEORETICAL PREDICTIONS.
THIS PRELIMINARY EXPERIENCE WAS AT THE SAME TIME VERY USEFUL TO DESIGN CONSIDERATIONS.

SIZING OF A FULL SCALE PROTOTYPE

A SIMULATION COMPUTER PROGRAMME - SET UP IN THE FRAME OF C.E.C. ENERGY R&D PROGRAMME : CONTRACT NR 11476-ESF - HAS BEEN USED TO SIZE A FULL SCALE PEBBLE BED STORAGE.

FOR A GIVEN DWELLING AND WEATHER DATA, THE MODEL CALCULATES THE HEATING REQUIREMENTS AND EVENTUAL ENERGY SAVINGS RELATIVE TO THE FOLLOWING CONFIGURATIONS :

* CONVENTIONAL ELECTRICAL HEATING ;
* SOLAR AIR HEATING WITHOUT STORAGE ;
* SOLAR AIR HEATING, WITH STORAGES OF DIFFERENT SIZES.

THE FIGURE GIVEN PAGE 23 SUMMARIZES THE RESULTS.

IT APPEARS FROM THIS STUDY THAT A REASONABLE FIGURE FOR THE STORAGE TIME CONSTANT IS ABOUT 9 HOURS.
IN THAT CASE, THE HEAT CAPACITY OF THE SOLID MATERIAL IS GIVEN BY (Qv IS THE AIR RATE IN m3/h) :

$$(M.CP) = 10700 \cdot Qv$$

THE STORAGE SYSTEM CONSIDERED HERE USES 6000 KG OF PEBBLES. THE DIMENSIONS OF THE BED ARE .6 m HEIGHT, 3.8 m LENGTH AND 2 m WIDTH.

THE MEASURED NTU VALUE IS LOWER THAN EXPECTED (18 INSTEAD OF 25), DUE TO LOCAL INHOMOGENEITIES OF BED POROSITY.
ON THE OTHER HAND, THE PRESSURE DROP HAS BEEN FOUND LOWER THAN PREDICTED, ALLOWING HIGHER VELOCITY IN ORDER TO INCREASE THE NTU FIGURE, AS DESIRED.

COST STUDY

A COST ANALYSIS IS GIVEN IN THE TABLE HEREUNDER (COSTS ARE IN FF - SEPT. 1979) :

	SINGLE FAMILY HOUSE	APARTMENT IN A 8-APARTMENT BUILDING
CONCRETE	863	211
ENVELOPE	927	300
INSULATION	208	99
PEBBLES	1973	1973
IRON, DIFFUSERS	1844	378
MISCELLANEOUS	417	205
TOTAL COST	6232	3166

THIS COMPARISON OUTLINES THE INTEREST OF GROUPING SEVERAL STORAGES AS IT OCCURS IN A MULTI-FAMILY APARTMENT BUILDING.

CONCLUSION

THE RECOMMENDED PARAMETERS FOR A FUTURE PROJECT SHOULD BE :

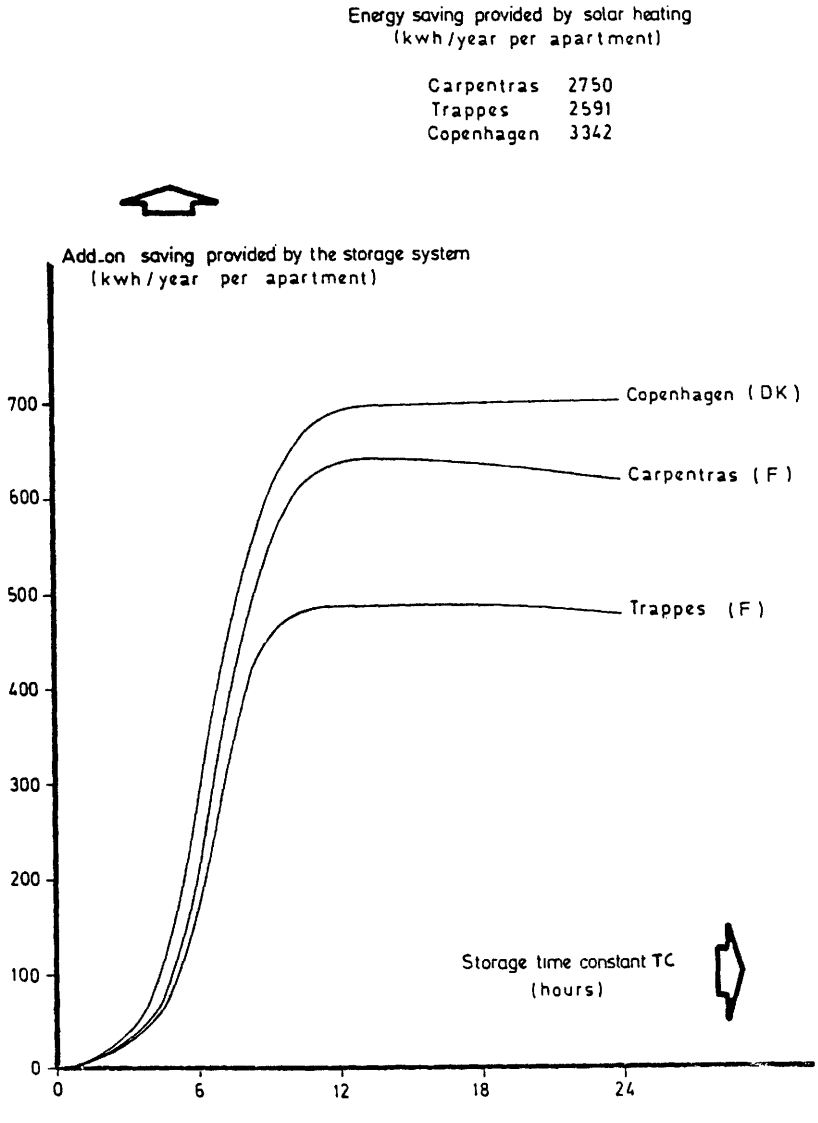
* PEBBLE SCREENING 40 TO 60 mm
* BED LENGTH 4.5 m
* AIR VELOCITY .17 m/s
* INSULATION THICKNESS .05 m

THESE FIGURES SHOULD PROVIDE :

* TIME CONSTANT 9 HOURS
* PRESSURE DROP 100 Pa
* NTU 25

THE DOMAIN OF INTEREST APPLIES TO A MULTIPLE APARTMENT BUILDING AND IN A REGION WHERE PEBBLES ARE AVAILABLE, IN ORDER TO REDUCE THE TOTAL COST.

- SAVINGS IN ENERGY CONSUMPTION VS. STORAGE TIME CONSTANT



TITLE : THEORETICAL AND EXPERIMENTAL STUDY
OF A 250 m3 WATER / PEBBLES STORAGE BASIN

CONTRACT NR : 515-78-1-ESF

ORGANIZATION : C.E.A.
SERVICE D'ETUDES ENERGETIQUES
B.P. 2
F - 91190 GIF sur YVETTE

PROJECT HEAD : J. BERNARD

AIM OF THE PROJECT

THE FEASIBILITY OF A LONG TERM STORAGE USING WATER AND PEBBLES HAS PREVIOUSLY BEEN DEMONSTRATED BY A SMALL SCALE MODEL (4 m3). THE OBJECTIVES OF THE PRESENT STUDY IS TO IMPROVE A MODELLING PROGRAMME AND TO BUILD A 250 m3 WATER/PEBBLES STORAGE.
THE THERMAL AND MECHANICAL BEHAVIOURS OF THE STORAGE UNIT AND THE SURROUNDING GROUND IS TO BE STUDIED UNDER THE FOLLOWING CONDITIONS :

* STORAGE UNIT CONNECTED TO A CONVENTIONAL BOILER;
* STORAGE UNIT CONNECTED TO A 90 m2 SOLAR COLLECTORS ARRAY

DESCRIPTION

A VERTICAL WALL CYLINDER (9 m DIAMETER X 4 m DEPTH) WAS EXCAVATED AND TIMBERED WITH 3 cm THICK WOOD BOARDS. A WATERPROOF RUBBER LAYER WAS SET ON THE BOTTOM AND ALONG THE WALL, AND PROTECTED ON BOTH SIDES BY A NON-WOVEN ANTIPUTRECING MATERIAL. THE PEBBLES (20 - 40 mm) WERE PLACED CAREFULLY AND THE WATER PIPE SYSTEM WAS SET IN THE BASIN.
AFTER COMPLETE FILLING WITH PEBBLES, AN INSULATING LAYER WAS PUT ON THE TOP OF THE STORAGE AND THE WHOLE SYSTEM WAS COVERED WITH EARTH.

A SCHEMATIC VIEW OF THE UNIT IS GIVEN NEXT PAGE.

56 THERMOCOUPLES HAVE BEEN DISTRIBUTED AT 6 DIFFERENT DEPTHS IN THE STORAGE, WHILE 50 OTHER THERMOCOUPLES WERE PLACED IN THE SURROUNDING GROUND.

ALL THE DATA ARE TRANSMITTED TO AN INSTRUMENT STATION SITUATED IN THE CENTER OF THE STORAGE AREA.
ALL THERMOCOUPLE DATA ARE RECORDED ON MAGNETIC TAPE AND/OR GRAPHICAL RECORDERS.

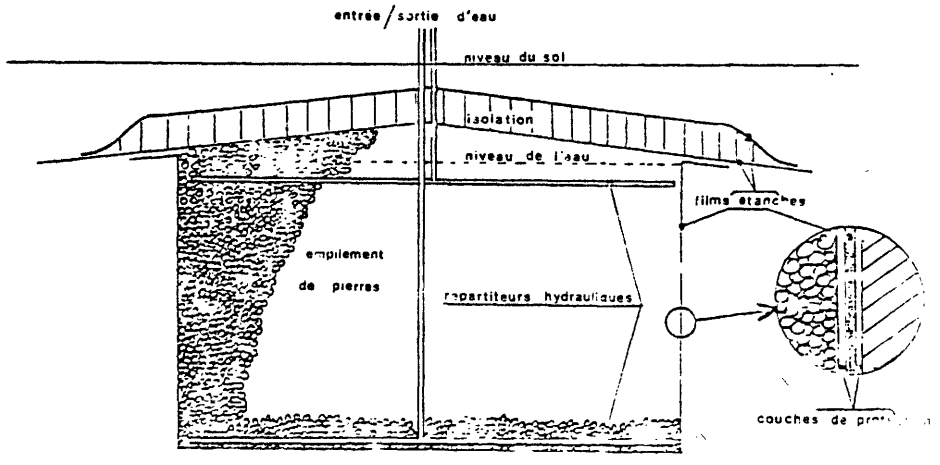


Figure 1 - Schéma de principe

CHARGING PHASE

A HOT WATER (70 C) FLOW RATE OF 250 TO 400 LITERS/HOUR HAS BEEN FLOWING THROUGH THE STORAGE UNIT DURING 45 DAYS. THIS REPRESENTS A TOTAL AMOUNT OF ENERGY OF 18000 kWh.

FROM THE 25TH DAY, THE TEMPERATURE RISE AT THE BOTTOM BECOMES LESS IMPORTANT, AND AT THE 30TH DAY, A CONSTANT TEMPERATURE IS OBTAINED, WHILE THE THERMAL POWER BEING SUPPLIED IS 6 kW. THIS FIGURE THUS CORRESPONDS TO THE THERMAL LOSSES OF THE UNIT.

THE TEMPERATURES IN A SAME HORIZONTAL LAYER ARE FOUND TO BE QUITE SIMILAR, REINFORCING THE ASSUMPTION OF A UNIFORM WATER FLOW DISTRIBUTION IN THE STORAGE.

HOWEVER, A STEP CHANGE OF WATER INLET TEMPERATURE INDICATES THAT AXIAL CONDUCTION MAY NOT BE NEGLECTED, AS IT WAS PREVIOUSLY ASSUMED IN THE MODEL.

AT THE END OF THE CHARGING PERIOD, THE TEMPERATURE MEASUREMENTS INDICATE THAT 11500 kWh HAVE BEEN EFFECTIVELY STORED BY THE SYSTEM, I.E. 64 % OF THE ENERGY SUPPLIED BY THE BOILER.

THE TEMPERATURE MEASUREMENTS IN THE SURROUNDING GROUND CONFIRM THE ASSUMPTION THAT ONLY A HEAT TRANSFER BY CONDUCTION OCCURS. THE THERMAL LOSSES CAN BE ESTIMATED AS FOLLOWS :

* TOP SURFACE 1 kW
* SIDE WALLS 2.5 kW
* BOTTOM 2 kW

DISCHARGE PERIOD

DUE TO SEVERAL PROBLEMS ARISED WITH APPARATUSES, THE MEASUREMENTS HAVE BEEN IMPRACTICABLE A FEW DAYS AFTER THE BEGINNING OF THIS PHASE. ONLY PARTIAL CONCLUSIONS CAN THUS BE DRAWN FROM THE DISCHARGE PERIOD.

AFTER 78 DAYS OF DISCHARGE, THE AVERAGE TEMPERATURE HAS BEEN 30 C, SHOWING THAT 7500 kWh HAVE BEEN REMOVED FROM THE SYSTEM.

AN OVERALL LOSS COEFFICIENT, RELATED TO THE STORAGE VOLUME AND WITH REFERENCE TO AN AVERAGE SOIL TEMPERATURE OF 10 C, CAN BE ESTIMATED EQUAL TO 0.5 W/(m3. C).

COUPLING OF THE STORAGE WITH SOLAR COLLECTORS

THE THERMAL LOSSES OF THE STORAGE SYSTEM BEING OF THE SAME MAGNITUDE AS THE OUTPUT OF ABOUT 72 m2 OF SOLAR COLLECTORS, IT WAS DECIDED TO ABANDON THE IDEA OF CONNECTING THE UNIT TO A 90 m2 SOLAR COLLECTORS ARRAY.
IN THE FUTURE, ANOTHER SOLAR BOILER PROVIDING 300 kWh/DAY AT 85 C WILL BE COUPLED WITH THE STORAGE SYSTEM.

COST STUDY

A SHORT COST STUDY HAS BEEN MADE AND LEADS TO A COST OF 325 FF (1979, TAXES EXCLUDED) PER CUBIC METER, UNDER NORMAL CONDITIONS. IF PUMPING OF AQUIFER IS REQUIRED DURING THE CONSTRUCTION, THIS COST MAY REACH 600 FF / m3.

CONCLUSION

A COMPARISON BETWEEN THE PROPOSED SYSTEM AND A WATER STORAGE SYSTEM SHOWS THAT THERE IS NO PREPONDERANT ARGUMENT LEADING TO THE SELECTION OF EITHER TWO SOLUTIONS.

A CHOICE MUST BE MADE BY CONSIDERATING OTHER FACTORS LIKE ENVIRONMENTAL CRITERIA OR LOCAL CONSTRAINTS.

TITLE : FEASIBILITY STUDY ON A COMBINED SUMMER COOLING AND WINTER HEATING SYSTEM BASED ON A COMBINATION OF SOLAR ENERGY AND GROUND HEAT PUMPS

CONTRACT NR : 523-78-ESDK

ORGANIZATION : EUROPEAN HEAT PUMP CONSULTORS
27 VEDBENDVEJ
DK - 2900 HELLERUP

PROJECT HEAD : M. FORDSMAN

PUBLISHED AS MICROFICHE REPORT EUR 6701 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE AIM OF THE PRESENT PROJECT HAS BEEN TO MAKE A FEASIBILITY STUDY ON A SOLAR AUGMENTED GROUND HEAT PUMP COOLING AND HEATING SYSTEM.
THE ECONOMIC ADVANTAGE OF SUCH A SYSTEM SHOULD BE THAT THE SAME HEAT PUMP INSTALLATION CAN BE USED BOTH FOR COOLING IN THE SUMMER AND FOR HEATING IN THE WINTER, WHICH SHOULD MAKE THE TOTAL INSTALLATION SO CHEAP THAT IT MUST BE ASSUMED THAT IT SHOULD STAND A FAIR CHANCE OF COMPETING WITH TRADITIONAL EUROPEAN COOLING-HEATING SYSTEMS.

REQUIREMENTS

THE SYSTEM SHOULD BE INSTALLED IN A SEMI-DETACHED ONE FAMILY HOUSE OF 103 m2 OF FLOOR AREA (TWO STOREYS OF ABOUT 50 m2 EACH). HEAT LOSSES ARE 4.5 kW AT 20 C / -12 C.

THREE DESTINATIONS HAVE BEEN CHOSEN FOR THE STUDY : COPENHAGEN, PARIS AND MARSEILLE. THIS CHOICE IS REPRESENTATIVE OF EUROPEAN CLIMATE.

THE FACTORS DETERMINING THE COOLING AND HEATING LOAD OF THE HOUSE ARE THE FOLLOWING :

* TRANSMISSION LOSS THROUGH THE EXTERIOR ENVELOPE
* VENTILATION LOSSES (200 m3/HOUR)
* CONTRIBUTION OF HEAT FROM THE SUN THROUGH THE WINDOWS
* HEAT FROM ELECTRICAL APPLIANCES AND PERSONS (18 kWh/DAY)
* HEAT ACCUMULATION (PRESENT HOUSE IS A HEAVY CONSTRUCTION)

THE HEATING AND COOLING LOADS HAVE BEEN CALCULATED ON A MONTHLY BASIS. ANOTHER COMPUTATION WITH TWO DAYS INTERVAL SHOWS ONLY 5 % DIFFERENCE WITH THE FORMER.
FINALLY, THE ROOMS ARE SUPPOSED TO BE KEPT AT 20 C (WINTER) AND 24 C (SUMMER). HOT WATER REQUIREMENT IS 4000 kWh/YEAR.

COMPUTER MODEL

VERY ACCURATE BUT COMPLICATED SIMULATION PROGRAMMES DO EXIST. HOWEVER, IT WAS FOUND THAT FOR NORMAL ENGINEERING PRACTICE, THERE IS A NEED FOR SIMPLIFIED COMPUTER MODEL, WHICH COULD BE APPLIED ON A TI PROGAMMABLE 59 OR THE LIKE.
THE SIMPLIFIED MODEL COMPRISED THREE MAIN ELEMENTS :

* THE HOUSE * THE SOLAR COLLECTOR * THE GROUND

THE COMPLETE SET OF EQUATIONS IS GIVEN IN THE REPORT, TOGETHER WITH THE FLOWDIAGRAM OF THE PROGRAMME, FOR USE ON TI-59.

THE RESULTS ARE FOUND TO BE EXACT ENOUGH, BY COMPARISON WITH A MUCH MORE SOPHISTICATED FINITE ELEMENTS MODEL. SO, IT WAS DECIDED THAT THE STUDY COULD CONTINUE BY USING THE SIMPLIFIED CALCULATION PROCESS.

COMPUTER CALCULATIONS

BY RUNNING THE CALCULATIONS FOR TEN CONSECUTIVE YEARS IT WAS FOUND THAT THE RESULTS VARIED STRONGLY FOR THE FIRST TWO YEARS, BUT DURING THE THIRD AND THE FOURTH YEARS THERE WERE ONLY SMALL VARIATIONS. FROM THE FIFTH YEAR AND ONWARDS THERE WERE NO MORE VARIATIONS IN THE GROUND TEMPERATURES.
THIS OBSERVATION CORRESPONDS TO OTHER THEORETICAL CALCULATIONS AND PRACTICAL MEASUREMENTS UNDERTAKEN IN DENMARK. THEREFORE SUBSEQUENT CALCULATIONS WERE MADE FOR THE THIRD YEAR ONLY.

THE FIGURE PAGE -5- SHOWS THE ENERGY CONSUMPTION AND THE C.O.P. FOR THE HEAT PUMP AND CIRCULATION PUMPS THAT HAVE BEEN OBTAINED FOR VARIOUS COLLECTOR AREAS AND GROUND PIPE LENGTHS FOR THE THREE DESTINATIONS.

THE RESULTS SHOW THAT, DUE TO THE HEAT TRANSFER PROCESS IN THE GROUND, SUCH A SYSTEM IS USEFUL AS AN ACCUMULATOR OF LOW TEMPERATURE ENERGY.

ECONOMIC CALCULATIONS

THE OPERATIONAL ANNUAL EXPENSES HAVE BEEN CALCULATED FOR THE THREE DESTINATIONS.
THE CHEAPEST COMBINATION IS A GROUND PIPE LENGTH OF 54 m, IN ALL CASES. BUT WHEREAS 5 m2 OF SOLAR COLLECTORS ARE NEEDED IN COPENHAGEN, PARIS AND MARSEILLE HAVE A SUFFICIENT GROUND TEMPERATURE TO ELIMINATE THE NECESSITY OF SOLAR COLLECTION.

IT SHOULD BE MENTIONED THAT THE SYSTEMS WITH THE LOWEST ANNUAL OPERATIONAL EXPENSES ARE NOT NECESSARILY THE SYSTEMS THAT GIVE THE HIGHEST ENERGY SAVING.

A COMPARISON OF THE INVESTMENT AND OPERATIONAL EXPENSES FOR TRADITIONAL SYSTEMS AND HEAT PUMP SYSTEMS FOR THE THREE DESTINATIONS HAVE BEEN MADE. IT IS FOUND THAT THE INVESTMENT ARE OF ABOUT THE SAME MAGNITUDE, WHEREAS OPERATIONAL COSTS ARE LOWER FOR HEAT PUMP SYSTEMS THAN FOR CONVENTIONAL INSTALLATIONS.

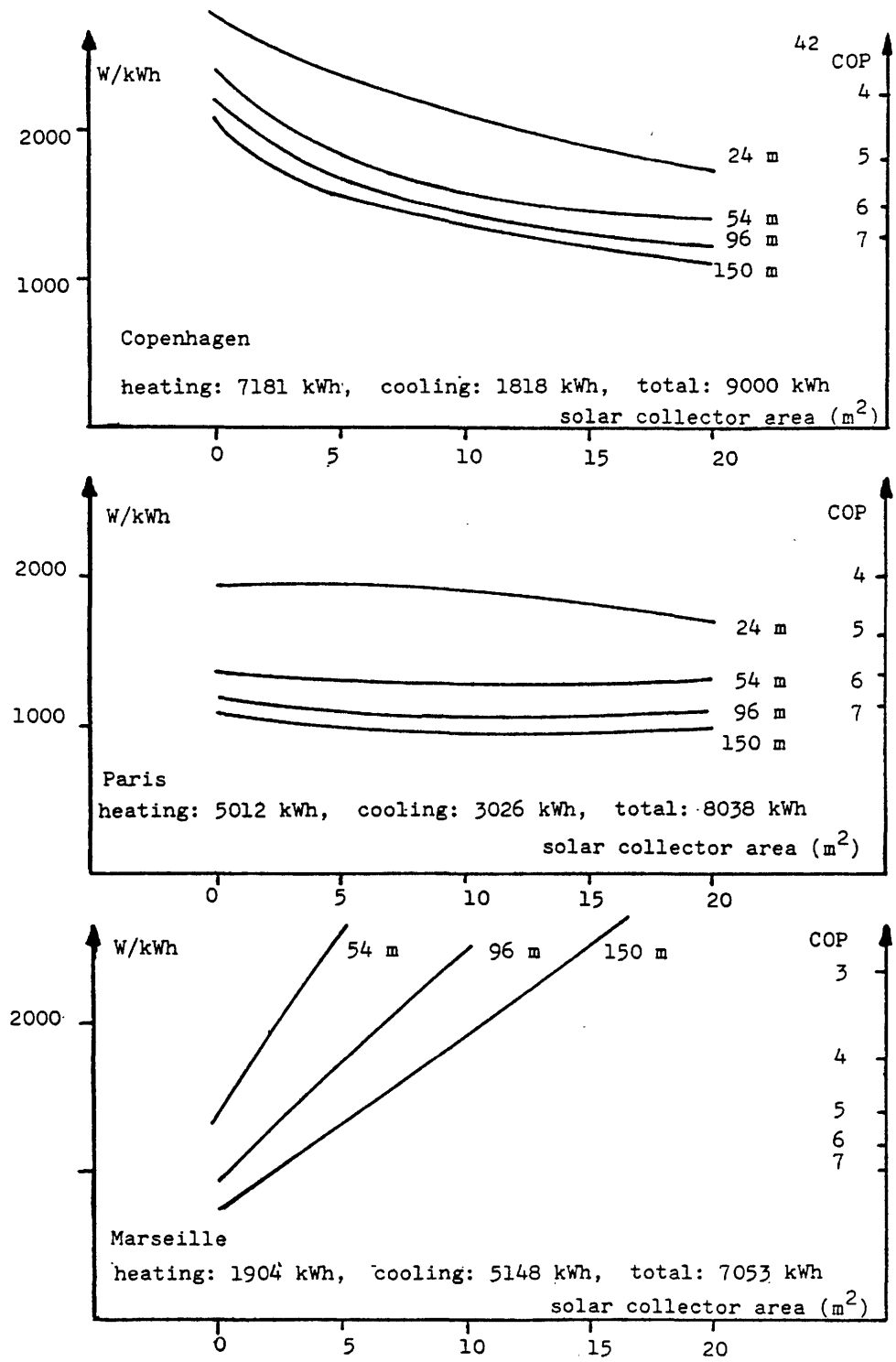
IN TERMS OF PRIMARY ENERGY CONSUMPTION, THE COMPARISON BETWEEN HEAT PUMP SYSTEMS AND CONVENTIONAL ONES LEADS TO THE FOLLOWING FIGURES : ENERGY SAVINGS ARE 24 % , 57 % AND 29 % FOR, RESPECTIVELY COPENHAGEN, PARIS AND MARSEILLE.

CONCLUSION

THE CALCULATIONS IN THE PRESENT STUDY ARE PURELY THEORETICAL, AND AS MANY ASSUMPTIONS HAVE NOT YET BEEN VERIFIED BY PRACTICAL EXPERIMENTS, THEY SHOULD BE TAKEN WITH A GRAIN OF SALT.
THEY DO, HOWEVER, SHOW CLEAR TRENDS, AND MAY SAFELY BE USED FOR COMPARING TWO THEORETICAL SYSTEMS.

THE ENERGY STORED BY THE GROUND MAKE POSSIBLE TO ACHIEVE HIGH C.O.P. VALUES - BETWEEN 5 AND 6 - FOR A COMBINED HEATING/COOLING HEAT PUMP INSTALLATION.

IT MUST BE KEPT IN MIND THAT THE STUDY HAS BEEN APPLIED TO A WELL INSULATED HOUSE. HOWEVER, IN THAT CASE, THE RESULTS SHOW AN INTEREST FOR HEAT PUMP SYSTEMS, FROM ENERGETIC AS WELL AS FROM ECONOMIC VIEWPOINTS.



Fig, 13 Energy consumption and COP of the heat pump for the three destinations.

TITLE : EUROPEAN SOLAR COLLECTOR
TESTING ACTIVITIES AND TEST METHODS

CONTRACT NR : 512-78-1-ESUK

ORGANIZATION : UNIVERSITY COLLEGE CARDIFF
SOLAR ENERGY UNIT
NEWPORT ROAD
GB - CARDIFF CF2 1TA , WALES

PROJECT HEAD : W.B. GILLETT

PUBLISHED AS MICROFICHE REPORT EUR 6815 PART 1 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT - PART 1

THE AIM OF THIS FIRST PART OF THE PROJECT IS TO ASSESS THE METHODS OF TESTING SOLAR COLLECTORS, ON THE BASIS OF THE ACTIVITIES OF TWENTY EUROPEAN LABORATORIES PARTICIPATING IN A COLLABORATIVE SOLAR COLLECTOR TESTING PROGRAMME COORDINATED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES.

PARTICIPANTS

THE LIST OF PARTICIPANTS IN THE PROGRAMME FOLLOWS :

LABORATORY	LOCATION	HEAD
FACULTE POLYTECHNIQUE DE MONS	MONS (B)	J. BOUGARD
KATHOLIEKE UNIVERSITEIT LEUVEN	HEVERLEE (B)	W.L. DUTRE
DENMARKS TECHNISKE HOJSKOLE	LYNGBY (DK)	S. SVENDSEN
INST. FOR INDUSTRIAL RESEARCH	DUBLIN (EIR)	J. GREGAN
TECHNISCHE PHYSICHE DIENST-TNO	DELFT (NL)	C. DEN OUDEN
LUXATOM	STEINFORT (L)	J. REMOVILLE
ELECTRICITE DE FRANCE	MORET S/LOING(F)	P. CHOUARD
COMMISS. A L'ENERGIE ATOMIQUE	SACLAY (F)	GUILLEMOT
CENTRE TECHNIQUE DES INDUSTRIES AERAULIQUES ET THERMIQUES	LYON (F)	LE VAGUERESE
ECOLE SUPERIEURE D'INGENIEURS DE MARSEILLE	MARSEILLE (F)	ROUX
POLITECNICO DI TORINO	TORINO (I)	C. BOFFA
IDEM AND FIAT	TORINO (I)	KALHEF
INDUSTRIE A. ZANUSSI	PORDENONE (I)	M. FERUGLIO
CENTRO PER LA RICERCA APPLICATA ALL'IMPIGIO DELL'ENERGIA SOLARE	VERONA (I)	D. BRAGGION
BROWN BOVERI & CIE	HEIDELBERG (D)	H. BIRNBREIER
INSTITUT FUR RAUMSIMULATION	KOLN (D)	W. LEY
KERNFORSCHUNGSANLAGE - IKP	JULICH (D)	H.J. STEIN
BUILDING RESEARCH ESTABLISH.T	GARSTON (GB)	S.J. WOZNIAK

(CONTINUED)

UNIVERSITY COLLEGE CARDIFF	CARDIFF (GB)	W.B. GILLETT
JOINT RESEARCH CENTER (CEC) (TESTING AND GUIDANCE)	ISPRA (I)	E. ARANOVITCH

ONLY A BRIEF DESCRIPTION OF THE TEST FACILITY IS GIVEN FOR EACH LABORATORY. DETAILS OF THE INSTRUMENTATION USED FOR COLLECTOR TESTING HAS BEEN CONSIDERED OUTSIDE OF THE SCOPE OF THE REPORT.

THE RECOMMENDATIONS DOCUMENT

"THE RECOMMENDATIONS FOR EUROPEAN SOLAR COLLECTOR TEST METHODS" DOCUMENT RESULTED FROM THE NEED TO DOCUMENT THE EXPERIENCE GAINED BY PARTICIPANTS IN THE CEC PROGRAMME AND TO MAKE DEFINITE RECOMMENDATIONS FOR STANDARDIZING METHODS OF TESTING.
THE DOCUMENT DEALS ONLY WITH COLLECTORS WHICH EMPLOY A LIQUID AS HEAT TRANSFER MEDIUM. CONCENTRATING DEVICES AND AIR HEATERS ARE TEMPORARILY EXCLUDED.
TESTS FOR STEADY STATE AND TRANSIENT PERFORMANCE, HEAT LOSS, THERMAL CAPACITY AND PRESSURE DROP ARE INCLUDED, TOGETHER WITH INSTRUMENTATION REQUIREMENTS AND A STANDARD FORMAT FOR THE PRESENTATION OF RESULTS.

THE MAIN SECTIONS OF THE DOCUMENT ARE :
- UNITS AND SYMBOLS. - DEFINITIONS. - COLLECTOR MOUNTING AND LOCATION. - THE TEST INSTALLATION. - INSTRUMENTATION FOR USE IN COLLECTOR TESTING. - TEST METHODS. -TEST METHODS UNDER DEVELOPMENT.

ROUND ROBIN RESULTS

SEE PART 3 OF THE PROJECT, BELOW.

METHODS OF DETERMINING THE COLLECTOR THERMAL CAPACITY

A STUDY OF ALL THE EXISTING PROPOSED METHODS OF DETERMINING THE COLLECTOR THERMAL CAPACITY WAS UNDERTAKEN AND DOCUMENTED IN A COMMON FORMAT UNDER THE SECTION ENTITLED "TEST METHODS UNDER DEVELOPMENT" OF THE DOCUMENT MENTIONED ABOVE.
MANY PROCEDURES PROPOSED WERE SIMILAR AND EVENTUALLY 8 METHODS WERE IDENTIFIED FOR INCLUSION IN THE RECOMMENDATIONS DOCUMENT.

THE FACULTE POLYTECHNIQUE DE MONS UNDERTOOK A PROGRAMME OF COMPARATIVE TESTING FOR THERMAL CAPACITY MEASUREMENT.
THE WORK SHOWED THAT THE DIFFERENCES BETWEEN THE THERMAL CAPACITY VALUES OBTAINED USING THE DIFFERENT METHODS WERE SMALL, AND FELL CLEARLY INTO TWO GROUPS. IT IS ANTICIPATED THAT NO MORE THAN TWO METHODS WILL BE INCLUDED IN THE PUBLISHED VERSION OF THE RECOMMENDATIONS DOCUMENT.
FROM THEIR EXPERIENCE, THE PREFERED METHOD IS THE INTEGRAL-ONE.

CALIBRATION METHODS

RECOMMENDED METHODS OF CALIBRATION ARE PROPOSED. PARTICULAR ATTENTION IS PAID TO THE MEASUREMENT OF SOLAR IRRADIANCE, OF FLUID FLOWRATE AND TEMPERATURE, AS THESE ARE DIRECTLY USED IN THE COMPUTATION OF THE COLLECTOR EFFICIENCY.

THE OVERALL FACILITY CALIBRATION IS ALSO COMMENTED. THE EQUIPMENT REQUIRED IN ADDITION TO THAT ALREADY AVAILABLE IN THE TEST FACILITY CONSISTS OF AN INSULATED ELECTRICAL WATER HEATER, INSTALLED IN PLACE OF A COLLECTOR IN THE TEST FACILITY.

PYRANOMETER CALIBRATION

SEE PART 2 OF THIS PROJECT.

SOLAR SIMULATORS

ALTHOUGH SOLAR SIMULATORS PRESENT THE OPPORTUNITY TO TEST THE FULL RANGE OF PERFORMANCE CHARACTERISTICS IN A SHORT PERIOD OF TIME, THERE ARE SEVERAL REASONS OF UNREPRESENTATIVITY OF THE OUTDOOR TESTING :

* INCORRECT RADIATION SPECTRUM ;
* NON-UNIFORMITY OF THE RADIATION INTENSITY OVER THE COLLECTOR
* DIVERGENCE OF THE RADIATION BEAM ;
* UNREPRESENTATIVE DIFFUSE COMPONENT OF THE RADIATION ;
* INCORRECT FIELD OF VIEW TEMPERATURE ;
* UNREPRESENTATIVE AMBIENT AIR TEMPERATURE ;
* UNREPRESENTATIVE COLLECTOR INCLINATION.

WITHIN THE GROUP THERE ARE PRESENTLY EIGHT OPERATIONAL SOLAR SIMULATORS THAT ARE BEING USED FOR COLLECTOR TESTING. THESE ARE AT THE FOLLOWING LABORATORIES :

* FACULTE POLYTECHNIQUE DE MONS
* TECHNICAL UNIVERSITY OF DENMARK
* ELECTRICITE DE FRANCE
* COMMISSARIAT A L'ENERGIE ATOMIQUE
* CETIAT
* ZANUSSI
* UNIVERSITY COLLEGE CARDIFF
* DFVLR
* JOINT RESEARCH CENTER (C.E.C.).

CONCLUSIONS

THE DOCUMENTING OF THE RECOMMENDATIONS FOR COLLECTOR TESTING HAS RESULTED IN CONSIDERABLE AGREEMENT AND STANDARDIZATION BETWEEN LABORATORIES AND INDIRECTLY BETWEEN NATIONAL TESTING ORGANIZATIONS.

AGREEMENT WAS REACHED ON A RECOMMENDED SET OF SYMBOLS AND UNITS FOR SOLAR ENERGY QUANTITIES.

A STANDARD FORMAT SHEET FOR PRESENTING THE RESULTS OF COLLECTOR TESTING WAS ALSO AGREED UPON BY THE GROUP. THIS WAS SUBSEQUENTLY ADOPTED BY THE INTERNATIONAL ENERGY AGENCY COLLECTOR TESTING GROUP.

ONE OF THE MAIN RESULTS OF THE PROGRAMME HAS BEEN THE INITIATION OF FURTHER RESEARCH AND INVESTIGATIONS, INTO THE EFFECT OF SKY TEMPERATURE, THE EQUIVALENCE OF TEST METHODS AND INTO METHODS OF PYRANOMETER CALIBRATION.

AIM OF THE PROJECT - PART 2

THIS PART OF THE WORK IS DEVOTED TO THE EVALUATION OF CM2 AND CM5 MODELS OF KIPP & ZONEN SOLARIMETERS. IT HAS BEEN UNDERTAKEN IN ORDER TO SUPPORT THE RESULTS OF A COMPARATIVE CALIBRATION WHICH WAS PERFORMED AT H.M. METEOROLOGICAL OFFICE (UK) IN 1978, FOR THE PARTICIPANTS OF A COLLABORATIVE COLLECTOR TESTING PROGRAMME COORDINATED BY THE C.E.C..

INSTRUMENT CHARACTERISITICS

THE DESIGN AND OPERATING BEHAVIOUR OF KIPP SOLARIMETERS ARE DISCUSSED; THE ERROR CAUSED BY THE OMISSION OF A RADIATION SHIELD IS OUTLINED.

THE INSTRUMENT PROPERTIES CAN BE SUMMARIZED AS FOLLOWS :

* LINEARITY : CM5 : +/- 1 % ; CM2 : -2 TO -5 %
* RESPONSE TO CHANGES IN AMBIENT TEMP. : -0.15 % PER C (CM5)
* INFLUENCE OF THE WIND : SMALL
* COSINE RESPONSE : DISAGREEMENT CAUSED BY THE FACT THAT IT VARIES WITH AZIMUTH OF THE DETECTOR
* INFLUENCE OF TILTING : MAX 1.6 TO 3 % IN RESPONSE AT ABOUT 70 DEG FROM NORMAL ; THE EFFECT OF TILT IS LESS AT HIGH

INTENSITIES THAN AT LOW.

SOLAR RADIATION REFERENCE SCALES

IT IS IMPORTANT TO KNOW TO WHICH REFERENCE STANDARD ANY GIVEN SOLAR RADIATION INSTRUMENT HAS BEEN CALIBRATED.
IN 1956, THE INTERNATIONAL PYRHELIOMETRIC SCALE (I.P.S. 1956) WAS CREATED FROM THE TWO SCALES IN USE AT THIS TIME.
THIS SCALE WAS RE-ESTABLISHED IN 1975 AND IS KNOWN AS "I.P.S. NOW IN USE".

IN 1975, IT WAS AGREED BY THE WORLD METEOROLOGICAL ORGANIZATION THAT A CAVITY RADIOMETER SHOULD PROVIDE THE WORLD REFERENCE WITH EFFECT FROM JULY 1981, AND THAT A NEW SCALE, THE WORLD RADIOMETRIC REFRENCE (W.R.R.), SHOULD BE ESTABLISHED WHICH WOULD BE 2.2 % HIGHER THAN I.P.S. "NOW IN USE".
ANY INSTITUTE MAY ADOPT EITHER THE I.P.S. OR THE W.R.R. SCALE UNTIL 1981 SO LONG AS THEY STATE WHICH ONE THEY ARE USING.

IT MAY BE REASONABLY ASSUMED THAT THE KIPP & ZONEN REFERENCE SOLARIMETER HAS BEEN MAINTAINED IN ACCORDANCE WITH I.P.S..

CALIBRATIONS

THE CALIBRATION METHODS USED IN UK AND BY KIPP & ZONEN ARE DESCRIBED AND DISCUSSED. FOR CM2 MODELS, THE CALIBRATIONS INDICATE THAT A SCATTER OF UP TO +/- 2 % IS LIKELY FOR ANY GIVEN INSTRUMENT.
THE REPORT GIVES THE RESULTS OF THE CALIBRATION OF FOURTEEN KIPP CM5 BELONGING TO THE PARTICIPANTS IN THE COLLABORATIVE PROGRAMME ON COLLECTOR TESTING.
THE MEAN DIFFERENCE WITH KIPP & ZONEN CALIBRATION IS -3.5 % .

CONCLUSIONS

THE KIPP SOLARIMETER IS A VERY SENSITIVE INSTRUMENT, AND MAY BE EASILY INFLUENCED BY ENVIRONMENTAL PARAMETERS OTHER THAN SOLAR RADIATION. IT SHOULD ALWAYS BE PROTECTED BY A RADIATION SHIELD AND THIS MAY NEED TO BE EXTENDED WHEN THE DETECTOR IS TILTED.

AIM OF THE PROJECT - PART 3

THIS PART OF THE COLLABORATIVE PROGRAMME IS TO PRESENT THE PERFORMANCES OF THREE SOLAR COLLECTORS, MEASURED BY THE TWENTY LABORATORIES PARTICIPATING IN THE ROUND ROBIN.

THE MEASUREMENTS DEAL WITH : * THE INSTANTANEOUS EFFICIENCY ; * THE EFFECTIVE THERMAL CAPACITY ; * THE GLOBAL HEAT LOSS COEFFICIENT ; * THE FLUID PRESSURE DROP.

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTORS WERE DETERMINED BY FOUR TEST PROCEDURES :

* NBS METHOD (OUTDOOR QUASI STEADY-STATE)
* BSE METHOD (COMBINED INDOOR/OUTDOOR)
* AFNOR METHOD (REFERENCE QUASI STEADY-STATE CONDITIONS METH.)
* TRANSIENT METHOD.

THE COLLECTORS TESTED

THE COLLECTORS TESTED REPRESENT THE MAIN TYPES OF FLAT-PLATE LIQUID HEATING COLECTORS COMMERCIALLY AVAILABLE.

* "CEC1" : SINGLE-GLAZED ; NON-SELECTIVE
* "CEC2" : DOUBLE-GLAZED ; NON-SELECTIVE
* "CEC3" : SINGLE GLAZED ; SELECTIVE.

THEIR MAIN CHARACTERISITICS ARE TABLED HEREUNDER :

	CEC1	CEC2	CEC3
COVER PLATES (GLASS)	1	2	1
ABSORBER MATERIAL	STAINLESS ST.	COPPER	STEEL
ABSORPTANCE	.95	.95	.94
EMITTANCE	.92	.92	.15
REAR INSULATION	MINERAL WOOL	- POLYURETHANE FOAM -	
INSUL. THICKNESS	5 CM	5 CM	8 CM
CASE MATERIAL	GALVAN. STEEL	- ALUMINIUM -	
APERTURE AREA (M2)	1.67	2.3	2.02
CASE THICKNESS (CM)	8.5	14.3	15.3

RESULTS

THE INSTANTANEOUS EFFICIENCY CURVES DETERMINED BY EACH PARTICIPANT ARE GIVEN IN THE REPORT. ALL THE DATA POINTS ARE SHOWN COLLECTIVELY IN THE FIGURE NEXT PAGE.

A LEAST SQUARE FIT GIVES THE FOLLOWING EFFICIENCY CURVES :

* CEC1 $\eta = .755 - .567\ T - .027\ T^{**2}$
* CEC2 $\eta = .577 - .434\ T + .002\ T^{**2}$
* CEC3 $\eta = .842 - .660\ T + .105\ T^{**2}$

(T IS THE REDUCED TEMPERATURE = 10(DT)/G).

DISCUSSION AND CONCLUSION

THE SCATTER IN THE DATA ARE CAUSED BY THE INFLUENCE OF THE ENVIRONMENT. IT IS APPARENT THAT ENVIRONMENTAL PARAMETERS DO NOT ACCOUNT FOR ALL THE SCATTER OF DATA, AND THAT A SIGNIFICANT DIFFERENCE MAY BE EXPECTED IN THE PERFORMANCE CHARACTERISTICS MEASURED FOR THE SAME COLLECTOR BY TWO DIFFERENT LABORATORIES.

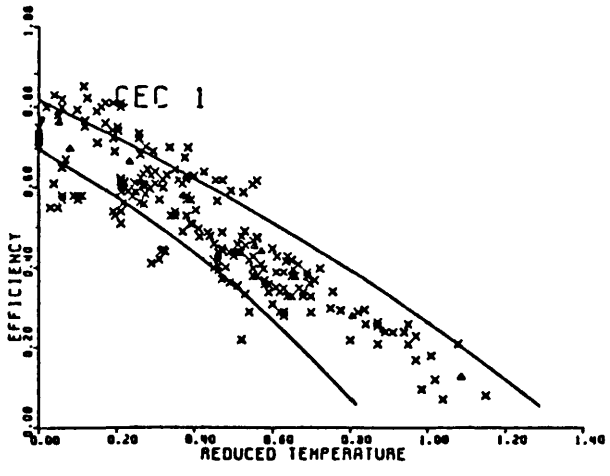


Fig. 16 Data Enclosed By The Environmental Extremes Of Table 5. - CEC 1

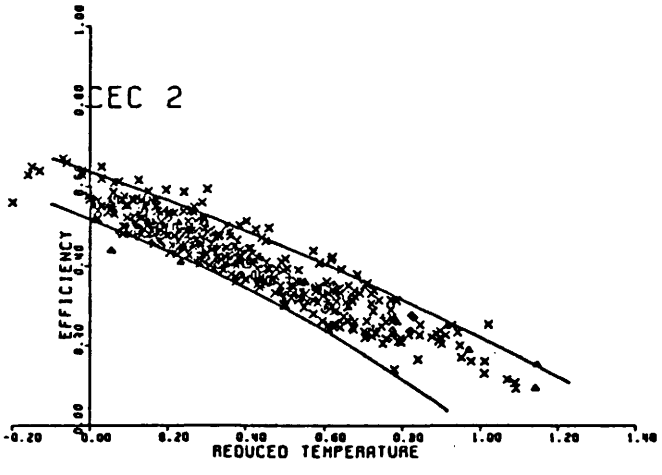


Fig. 17 Data Enclosed By The Environmental Extremes Of Table 5. - CEC 2

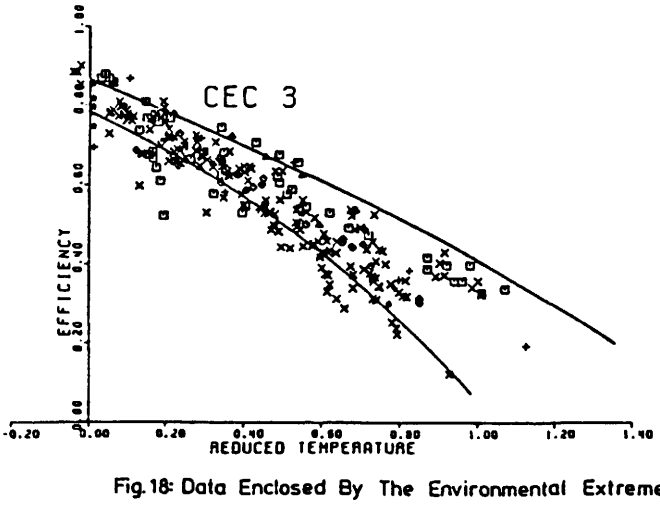


Fig. 18: Data Enclosed By The Environmental Extremes Of Table 5. - CEC 3

THE SCATTER OF DATA WAS ATTRIBUABLE TO SYSTEMATIC ERRORS IN MEASUREMENT AND METHOD OF TESTING. SCATTER MAY ALSO HAVE BEEN INTRODUCED BY VARIATIONS IN THE PROPERTIES OF THE DISTRIBUTED COLLECTORS. THE RESULTS OF TESTING USING SIMULATED SOLAR RADIATION WERE MORE REPRODUCIBLE THAN THOSE FOR OUTDOOR TESTING.

ANYHOW, ALL THE PROCEDURES USED WERE SUCCESSFUL IN CLEARLY DEMONSTRATING THE DIFFERENT CHARACTERISTICS OF THE THREE TYPES OF COLLECTORS TESTED AND THE COLLECTIVE DATA FROM ALL THE FACILITIES DEMONSTRATED THAT IT WAS POSSIBLE TO DISTINGUISH BETWEEN THE COLLECTORS BY MEANS OF STEADY STATE PERFORMANCE TESTING DESPITE THE SCATTER IN INDIVIDUAL MEASUREMENTS.

TITLE : DESIGN, CONSTRUCTION AND FIRST OPERATION OF THE BELGIAN SOLAR PILOT TEST FACILITY

CONTRACT NR : 607-78-1-ESB

ORGANIZATION : KATHOLIEKE UNIVERSITEIT LEUVEN
CELESTIJNENLAAN 300 A
B - 3030 HEVERLEE

PROJECT HEAD : W.L. DUTRE

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INTRODUCTION

HAVING DISCUSSED THE BACKGROUND AND REASONS FOR THIS CONTRACT THE LOGIC OF THE PILOT TEST FACILITY, WHICH IS ONE OF EIGHT, IS EXPLAINED. THE BELGIAN P.T.F., LIKE ALL EIGHT, CONTAINS TWO DISTINCT SOLAR SYSTEMS (SS1 AND SS2) THE FIRST BEING THE SAME AS THE OTHER SEVEN AND THE SECOND DIFFERENT.

DESCRIPTION OF SYSTEM 1

A DESCRIPTION OF THE SYSTEM GIVES SCHEMATIC DIAGRAMS, PHOTOGRAPHS AND A PARTS LIST. THE LOAD EXPERIENCED BY THE P.T.F., BY A FICTITIOUS HOUSE COMMON TO ALL EIGHT PTF'S, IS USED TO CONTROL THE PHYSICAL SIMULATOR.

HEAT IS DISSIPATED TO ATMOSPHERE WITH A FANCOIL UNIT. THE PHYSICAL CHARACTERISTICS OR DESCRIPTORS OF ALL RELEVANT COMPONENTS WERE MEASURED TO ENABLE INCORPORATION OF RESULTS INTO THE ACTIVITIES OF THE EUROPEAN MODELLING GROUP, AND ARE GIVEN IN DETAIL.

DESCRIPTION OF SYSTEM 2

SYSTEM 2 WAS DESIGNED TO PROVIDE PREHEATING OF DOMESTIC HOT WATER (DHW), TO PERMIT THE USE OF A HEAT PUMP AND TO ENCOURAGE STORAGE TANK STRATIFICATION, WHILE PRESERVING THE SAME COLLECTOR TYPE AND AREAS AS SS1 AND THE SAME HOUSE LOAD. IN OPERATION THE STRATIFIED STORE PROVIDES HOT WATER DIRECTLY FOR SPACE HEATING IF POSSIBLE ; IF THE STORE IS TOO COLD, WATER TEMPERATURE IS EFFECTIVELY BOOSTED BY THE HEAT PUMP.

AN AUXILIARY SYSTEM IS PROVIDED FOR SPACE HEATING AND ANOTHER FOR THE DHW PRE-HEAT TANK, WHICH IS SET AT 50 "C. THE HOUSE LOAD SIMULATED IS 10 KW MAXIMUM HAVING A LOWER DISTRIBUTION TEMPERATURE THAN SS1 AND A HIGHER FLOW RATE. HOWEVER THE SAME

HOUSE IS SIMULATED IN SS1 AND SS2 USING A COMMON LOAD CALCULATION. THE SS2 DESCRIPTORS ARE GIVEN IN DETAIL.

CENTRAL CONTROL AND MEASURING SYSTEM

A COMPUTER SYSTEM WITH PERIPHERAL MEASURING CONTROL AND DATA STORAGE DEVICES IS USED TO MEASURE PHYSICAL VARIABLES, TO SIMULATE THE THERMAL LOAD OF THE HOUSE AND TO CONTROL THE PHYSICAL LOAD SIMULATORS IN SS1 AND SS2.
DETAILS OF THE CENTRAL CONTROL SYSTEM ARE GIVEN.
RAPIDLY VARYING PARAMETERS ARE MEASURED EVERY MINUTE AND AVERAGED AT FIVE-MINUTE INTERVALS. LONG TERM DATA IS STORED ON NINE TRACK TAPE, AND ON CARTRIDGE AS HOURLY VALUES, FOR COMPARISON WITH OTHER PTF'S ; PRINTS-OUT ARE AVAILABLE.

PRELIMINARY TRIALS ON SS2

COMMISSIONING TESTS WERE PERFORMED IN ACCORDANCE WITH THE PROCEDURES LAID DOWN BY THE OVERALL PTF CO-ORDINATOR.

THE FIRST TEST SHOWED THAT THE PRIMARY LOOP AND THE DATA ACQUISITION SYSTEM FUNCTION CORRECTLY. A SERIES OF FIVE TRIALS WAS CARRIED OUT TO VERIFY OPERATION AND CALIBRATION OF THE LOAD SIMULATOR CIRCUITS AND RESPONSE WITHOUT HYSTERESIS TO STEP CHANGES. FINALLY THE HEAT REJECTION CIRCUIT WAS TESTED.
RESULTS OF ALL SEVEN TESTS ARE GIVEN.

OPERATIONAL VALIDATION OF SS1

DATA FROM SEVERAL MONTHS OPERATION ARE GIVEN BASED ON FIVE-MINUTE DATA. THEY SHOW GOOD AGREEMENT BETWEEN OBSERVED SYSTEM BEHAVIOUR AND THAT REQUIRED BY THE LOAD SIMULATION PROGRAM.
COMPARISONS BETWEEN MEASURED AND PREDICTED VALUES ARE MADE.

TITLE : THE GERMAN SOLAR PILOT TEST FACILITY -
DESIGN CONSTRUCTION AND FIRST PHASE OF OPERATION

CONTRACT NR : 610-78-3-ESD

ORGANIZATION : TECHNISCHE UNIVERSITAT BERLIN
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PROJECT HEAD : R. HANITSCH

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INTRODUCTION

THIS REPORT DESCRIBES THE DESIGN, CONSTRUCTION AND TESTING OF ONE OF EIGHT NOMINALLY IDENTICAL SOLAR PILOT TEST FACILITIES (PTF'S) THE DESIGN AND CONSTRUCTION OF A DIFFERENT SOLAR SYSTEM (SS2) AND THE OVERALL PROGRAMME MANAGEMENT STRUCTURE.

PRINCIPLE OF SS1

THE PTF CONSISTS OF A REAL FULL-SCALE SOLAR INSTALLATION HAVING A PHYSICALLY SIMULATED HOUSE HEATING LOAD, ALLOWING FOR OCCUPANCY. MEASURED DATA ARE COLLECTED ON THE PTF AND ON CLIMATIC CONDITIONS AND STORED IN A PRE-DETERMINED MANNER.
THE DESIGN OF THE SOLAR SYSTEM AND THE LOAD SUB-SYSTEM IS OUTLINED. A MICROPROCESSOR IS USED TO MONITOR RELEVANT DATA AND TO OPERATE THE PHYSICAL CONTROLS HAVING CALCULATEDTHEIR BEHAVIOUR IN ORDER TO MEET THE REAL BUT SIMULATED LOAD IN REAL TIME.
AN OUTLINE DESCRIPTION IS GIVEN OF THE MICROPROCESSOR SYSTEM.
A PHOTOGRAPHIC RECORD IS GIVEN OF THE CONSTRUCTION, DURING WHICH MINOR PROBLEMS WERE EXPERIENCED.

TRIALS

MEASUREMENTS WERE TAKEN TO EVALUATE THE SYSTEM EFFICIENCY, THE PERFORMANCE OF MAJOR COMPONENTS AND THEIR INTERACTIONS, THE SYSTEM CHARACTERISTICS AND ENVIRONMENTAL PARAMETERS. EXAMPLES OF ACTUAL DATA ARE GIVEN.

COMMISSIONING TESTS WERE CARRIED OUT IN ACCORDANCE WITH INSTRUCTIONS FROM THE PROGRAMME CO-ORDINATOR AND SYSTEM OPERATION WAS COMMENCED.

PRINCIPLE OF SS2

THE SECOND SOLAR SYSTEM SS2 CONTAINS TWO SUB-SYSTEMS A AND B. A IS A DOMESTIC HOT WATER SYSTEM WITH AN AUXILIARY HEATER, WHEREAS SUB-SYSTEM B HEATS AN UNDERFLOOR SYSTEM THROUGH A HEAT PUMP.
IN ADDITION WASTE HEAT FROM A LARGE TRANSFORMER IS USED AS A HOT SOURCE FOR THE HEAT PUMP.

DIAGRAMS AND PHOTOGRAPHS OF BOTH SUB-SYSTEMS ARE PRESENTED WITH THE PRINCIPLES OF OPERATION.

TECHNICAL ANNEXES GIVE DETAILS OF THE COLLECTORS USED AND OF BOTH SYSTEMS 1 AND 2.

TITLE : THE IRISH SOLAR PILOT TEST FACILITY

CONTRACT NR : 611-78-3-ESEIR

ORGANIZATION : INSTITUTE FOR INDUSTRIAL RESEARCH AND STDS
BALLYMUN ROAD
DUBLIN 9
(IRELAND)

PROJECT HEAD : I.J. COWAN

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INTRODUCTION

VARIOUS DIFFERENT APPROACHES TO THE STUDY OF SOLAR SYSTEMS ARE DESCRIBED LEADING TO THE DECISION TO BUILD A SERIES OF EIGHT HYBRID SOLAR PILOT TEST FACILITIES (PTF'S) EACH TO CONSIST OF TWO SUB-SYSTEMS.

THE FIRST SUB-SYSTEM (SS1) WAS SPECIFIED BY A CO-ORDINATOR TO BE THE SAME IN ALL EIGHT COUNTRIES AND TO HAVE COMPATIBLE DATA ACQUISITION AND CONTROL SYSTEMS, WHEREAS RELATIVE FREEDOM WAS ALLOWED IN THE DESIGN OF THE SECOND SUBSYSTEM (SS2).
RESULTS WERE MADE AVAILABLE TO VARIOUS MODELLING GROUPS FOR MODEL VALIDATION.

PRINCIPLES OF SS1

SS1 MAY BE DIVIDED INTO THREE SECTIONS : A REAL CIRCUIT CONTAINING COLLECTORS AND STORAGE, AN INTERFACE CIRCUIT FOR PHYSICAL SIMULATION OF HEATING LOADS AND A COOLING CIRCUIT TO REJECT THE SIMULATED LOAD.
AN OVERALL SCHEMATIC DIAGRAM SHOWS THE LAYOUT AND A DETAILED DESCRIPTION GIVES THE COMPONENTS USED BY TYPE AND RELEVANT PARAMETERS. MODIFICATIONS WERE MADE TO THE ORIGINAL PIPEWORK LAYOUT TO OVERCOME PROBLEMS SUCH AS AIR LEAKAGE AND CAVITATION DUE TO A LACK OF NET POSITIVE SUCTION HEAD.

MEASUREMENT AND CONTROL

A DATA ACQUISITION AND CONTROL SYSTEM BASED ON A MICROCOMPUTER WAS USED, HAVING STORAGE ON TAPE CARTRIDGE TO FACILITATE DATA EXCHANGE WITH OTHERS.
A SCHEMATIC AND COMPONENTS LIST ARE PROVIDED TOGETHER WITH A DESCRIPTION OF THE CONTROL FUNCTIONS.

A SAMPLING ROUTINE MEASURED SPECIFIED VARIABLES BOTH METEOROLO-

GICAL AND OPERATIONAL AT ONE OR FIVE-MINUTE INTERVALS.
THE SIMULATED HOUSE LOAD WAS THEN CALCULATED AND CONTROL SIGNALS SENT TO PHYSICALLY REMOVE THE CORRECT POWER FROM STORAGE.
A LIST OF VARIABLES MEASURED IS GIVEN, WITH AN ACCOUNT OF THE TAPE FORMAT.

SOME DETAILS ARE GIVEN OF VARIOUS TRANSDUCERS USED, THEIR CONVERSION FACTORS AND ACCURACIES. THE DESIGN OF THE HOUSE, WHOSE THERMAL PERFORMANCE IS SIMULATED USING REAL-TIME METEOROLOGICAL DATA AS INPUTS, IS DESCRIBED.
THE THERMAL PERFORMANCE OF THE HEAT EMITTING CIRCUIT IN THE HOUSE IS NEXT SIMULATED, TO PROVIDE CONTROL FUNCTIONS FOR THE INTERFACE SECTION.
ALGORITHMS ARE DESCRIBED TO CONTROL THE CENTRAL MOTORIZED VALVE IN THE INTERFACE, AND SET POINTS.

PRINCIPLES OF SS2

SS2 WAS DESIGNED TO REPRESENT IRISH CONDITIONS AND TO TEST CERTAIN INNOVATIVE IDEAS. IT PROVIDES BOTH SPACE HEATING AND DOMESTIC HOT WATER.
A DIRECT HEATING SOLAR SYSTEM WAS USED, CONTAINING NO ANTI-FREEZE. DRAIN DOWN OCCURED WHEN ENERGY WAS NOT BEING COLLECTED, GIVING A SIMPLER, CHEAPER AND MORE EFFICIENT SYSTEM.

COLLECTORS OPERATE EITHER IN PARALLEL OR IN SERIES PARALLEL, DEPENDING ON CONDITIONS, CHANGEOVER BEING AUTOMATIC.
STORAGE STRATIFICATION IS ENCOURAGED. INTERFACE CIRCUITS AND COOLING SIMILAR TO SS1 ARE PROVIDED.
A COMPONENTS LIST IS GIVEN FOR SS2.

DATA ACQUISITION AND CONTROL FUNCTIONS ARE PROVIDED BY THE SAME MICROCOMPUTER USED FOR SS1, WITH THE SAME PRIMARY VARIABLES BEING MEASURED.

A DIFFERENT HOUSE IS SIMULATED AND A DESCRIPTION IS GIVEN HERE, TOGETHER WITH THE PROFILE OF HOT WATER DRAW OFF.
A DESCRIPTION OF THE CONFIGURATION SWITCHING IS GIVEN.

PRELIMINARY TRIALS ON SS1

PRESCRIBED TESTS ON SUB-COMPONENTS OF SS1 ARE DESCRIBED AND SPECIMEN RESULTS GIVEN.
A FULL WEEK'S OPERATION UNDER LOAD WAS STORED ON TAPE. SPECIMEN RESULTS ARE GIVEN FROM THIS OPERATION.
GENERAL CONCLUSIONS ARE PRESENTED.

TITLE : THE DUTCH SOLAR PILOT TEST FACILITY

CONTRACT NR : 613-78-1-ESN

ORGANIZATION : TECHNISCH PHYSISCHE DIENST TNO-TH
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POSTBUS 155
NL - 2600 AD DELFT

PROJECT HEAD : E. VAN GALEN

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INTRODUCTION

THE CONCEPT OF A SOLAR PILOT TEST FACILITY (PTF) AND THE REASONS FOR CONSTRUCTING IT ARE EXPLAINED.
ONE PTF WAS BUILT IN EACH OF EIGHT E.E.C. STATES UNDER AN OVER-ALL PROJECT MANAGER, EACH PTF CONTAINING TWO SUB-SYSTEMS.

PRINCIPLES OF PTF 1

THE FIRST SUBSYSTEM WAS ESSENTIALLY THE SAME IN EACH INSTALLATION, AND COMPRISED SOLAR COLLECTORS AND A STORAGE TANK INSTALLED PRACTICALLY AND TESTED. A COOLING CIRCUIT DOWNSTREAM FROM THE TANK WAS CONTROLLED BY A MICROPROCESSOR, SIMULATING AN INHABITED HOUSE WHOSE HEATING LOAD DEPENDED ON THE WEATHER.

IN ADDITION THE MICROPROCESSOR CONTROLLED DATA ACQUISITION FOR THE INSTALLATON AND THE SECOND SUB-SYSTEM, WHICH PROVIDED SPACE HEATING AND DOMESTIC HOT WATER.

PRINCIPLES OF PTF 2

THE SECOND SUB-SYSTEM, USING MINERAL OIL AS A HEAT TRANSFER MEDIUM, HAD A STRATIFIED STORAGE TANK AND WAS SMALLER THAN SYSTEM 1. IT HAD A SIMULATED HOUSE LOAD OPERATED IN THE SAME MANNER AS SYSTEM 1, AND A DOMESTIC HOT WATER INSTALLATION HAVING A PRE-DETERMINED USE PROFILE.

A BRIEF DESCRIPTION OF THE DATA ACQUISITION AND CONTROL SYSTEM AND MEASURING DEVICES IS GIVEN. NO MAJOR PROBLEMS WERE ENCOUNTERED DURING THE ERECTION OF THE PTF.

PRELIMINARY TRIALS AND OPERATION

PRELIMINARY TRIALS WERE CARRIED OUT AS LAID DOWN BY THE OVERALL PROGRAMME CO-ORDINATOR IN ORDER TO TEST SUB-ASSEMBLIES. RESULTS OF THESE TRIALS ARE QUOTED.

THE INSTALLATION WAS THEN OPERATED AS A WHOLE AND MEASURED RESULTS COMPARED WITH THOSE PREDICTED. REASONABLE AGREEMENT WAS OBTAINED EXCEPT DURING CERTAIN TRANSIENT AND START-UP CONDITIONS. PARTICULAR PHYSICAL REASONS FOR THE DISCREPANCIES ARE DISCUSSED AND INVESTIGATIVE ACTION SUGGESTED. A BROAD OUTLINE OF FUTURE WORK IS GIVEN.

APPENDICES GIVE PHOTOGRAPHS, DRAWINGS, AND MATERIAL SPECIFICATIONS FOR THE INSTALLATION, AS WELL AS CONTROL ALGORITHMS AND EXAMPLES OF PRINTED RESULTS.

TITLE : HIGH PERFORMANCE COLLECTOR
FOR SMALL POWER STATION

CONTRACT NR : 525-78-1-ESD

ORGANIZATION : DORNIER SYSTEM GMBH
POSTFACH 1360
D - 7990 FRIEDRICHSHAFEN

PROJECT HEAD : K. SPEIDEL

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AIM OF THE PROJECT

THE PURPOSE OF THIS RESEARCH IS TO DEVELOP A HIGH PERFORMANCE SOLAR COLLECTOR TO BE USED IN SMALL POWER GENERATION OR COOLING PLANTS.

SELECTION OF A COLLECTOR

IT IS SHOWN THAT IN THE CASE OF MECHANICAL POWER GENERATION, AN ADEQUATE CHOICE OF THE SOLAR COLLECTOR CAN LEAD TO AN INCREASE OF THE OVERALL EFFICIENCY OF THE PLANT BY A FACTOR 4 TO 5.
THIS CAN BE ACHIEVED BY :

* INCREASING THE WORKING TEMPERATURE (130-150 DEG.C)
* KEEPING A HIGH COLLECTOR EFFICIENCY IN THAT TEMPERATURE RANGE (40-50 %)
* UTILIZING THE COLLECTOR DIRECTLY AS A BOILER.

THE SAME REQUIREMENTS ARE NECESSARY TO MAKE NH3/H2O ABSORPTION COOLING UNITS WORK EFFICIENTLY.

CONCENTRATING COLLECTORS

IN A FIRST PHASE, PARABOLIC CONCENTRATOR COLLECTORS HAVE BEEN INVESTIGATED. A MODELLING COMPUTER PROGRAMME HAS BEEN USED FOR THE STUDY OF THE INFLUENCE OF SEVERAL DESIGN PARAMETERS.

A LARGE DISCREPANCY BETWEEN THE PREDICTIONS AND EXPERIMENTAL RESULTS WAS OBSERVED, AND ATTRIBUTED ESSENTIALLY TO THE BAD OPERATION OF THE SUN-TRACKING SYSTEM AND TO THE IMPORTANCE OF DIFFUSED RADIATION.

FURTHERMORE, THIS TYPE OF COLLECTOR CANNOT MEET PRACTICAL REQUIREMENTS SUCH AS EASINESS OF TRANSPORT AND ASSEMBLING ON THEIR SITE.

FINALLY, CHOKING PROBLEMS ARE ENCOUNTERED WHEN THE COLLECTOR IS OPERATED AS A BOILER.

FLAT PLATE COLLECTORS

ONLY EVACUATED FLAT PLATE COLLECTORS CAN REACH THE PRESCRIBED TEMPERATURES WITH AN ACCEPTABLE EFFICIENCY.

A THEORETICAL ANALYSIS HAS BEEN CARRIED OUT TO EVALUATE CONVECTIVE AND CONDUCTIVE HEAT LOSSES UNDER VARYING INSIDE PRESSURE. THE HEAT TRANSFER BY CONDUCTION BEEING OF MUCH LOWER IMPORTANCE THAN BY CONVECTION, AN INTERNAL PRESSURE OF 1 TORR SEEMS TO BE ACCEPTABLE AND CAN BE MAINTAINED DURING SEVERAL YEARS (7-8) THANKS TO CONVENTIONAL VACUUM SEALING TECHNIQUES.

THE FINAL CHOICE LED TO AN EVACUATED TUBE COLLECTOR, AFTER VERIFICATION THAT THE OPTICAL LOSSES DUE TO THE CYLINDRICAL SHAPE OF THE GLASS CANNOT AFFECT SIGNIFICANTLY THE EFFICIENCY.

VAPORIZATION PROCESS

THE VAPORIZATION PROCESS TAKING PLACE IN THE COLLECTOR HAS BEEN EXPERIMENTALLY STUDIED.
IT WAS FOUND THAT A PARTIALLY FILLED TUBE PLACED IN VERTICAL OR TILTED POSITION IS NOT TO BE RECOMMENDED ; AN HORIZONTAL DISPOSITION GIVES BETTER RESULTS, BUT PREFERENCE MUST BE GIVEN TO A FILMWISE VAPORIZATION, WHICH CAN BE ACHIEVED EITHER IN A TUBE IN DIRECT CONTACT WITH THE ABSORBER, OR BY MAKING USE OF HEAT-PIPES TECHNIQUE.

DIFFERENT SOLUTIONS HAVE BEEN TRIED, IN ORDER TO GENERATE A FILM-STREAM. A SYSTEM USING FILTER MATERIALS HAS BEEN SUCCESSFUL, AND MUCH MORE SATISFACTORY THAN A SLOTTED TUBE.

FILM VAPORIZATION EXPERIMENTS HAVE BEEN CARRIED OUT WITH LiBr/ H2O SOLUTIONS. WITHOUT AN HEAT-PIPE, CRISTALLIZATION OCCURS IN THE SYTEM, MAKING THE COLLECTOR UNPROPER FOR THAT PURPOSE. WHEN WORKING WITH H2O/NH3 SOLUTIONS, SUCH PROBLEMS DO NOT EXIST BUT CORROSION QUESTIONS ARISE. NH3 FORBIDS THE USE OF ALUMINIUM OR COPPER IN THE COLLECTOR ; CAREFUL ATTENTION MUST THEN BE BRAUGHT TO THE CONSEQUENCES OF USING STEEL (TECHNOLOGY AND THERMAL PROPERTIES).

PROTOTYPE TESTING AND CONCLUSION

A PROTOTYPE OF THE EVACUATED TUBE COLLECTOR HAS BEEN BUILT AND TESTED PRIOR TO THE BUILDING OF A 9 m2-UNIT.

THE RESULTS OBTAINED STRESS THE IMPERATIVE NEED TO USE CONJOINTLY A LOW INTERNAL PRESSURE AND A SELECTIVE ABSORBER SURFACE, IN ORDER TO ACHIEVE THE REQUIRED SPECIFICATIONS.

THE COLLECTOR EFFICIENCY REACHES 46 % , WHEN :

* INTERNAL PRESSURE = 1 TORR
* ABSORBENT CHARACTERISTICS : $\alpha = .90$; $\varepsilon = .15$
* DT/I = (130-20)/800 = .1375 m2.K/W

TITLE : DEVELOPMENT OF A
SELECTIVE SURFACE VACUUM COLLECTOR

CONTRACT NR : 526-78-1-ESNL

ORGANIZATION : TECHNISCHE PHYSICHE DIENST TNO-TH
POSTBUS 155
NL - 2600 AD DELFT

PROJECT HEAD : H. DE WAAL - F. SIMONIS

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AIM OF THE PROJECT

IT IS THE AIM OF THE PROJECT TO DEVELOP A FLAT PLATE HIGH PERFORMANCE COLLECTOR WHICH CAN BE MANUFACTURED FOR A REASONABLE PRICE.
THE CONSTRUCTION IS THOUGH TO CONSIST OF A METAL BOX WITH A GLASS COVER HERMETICALLY SEALED TO IT.

TO OBTAIN AN ACCEPTABLE EFFICIENCY THE BOX CONTAINS TWO-DIMENSIONAL V-TROUGH CONCENTRATORS AND A HIGH QUALITY SPECTRAL SELECTIVE COATING ON THE ABSORBER. TO REDUCE HEAT LOSSES THE BOX HAS TO BE EVACUATED. THE SIDES OF THE V-TROUGHS SERVE AS SUPPORTS FOR THE GLASS PLATE TO PREVENT EXCESSIVE BENDING.

DESIGN STUDIES

ALL CAUSES OF HEAT LOSSES HAVE BEEN INDIVIDUALLY CONSIDERED, AND EACH OF THEM HAS RECEIVED AN IMPROVEMENT IN ORDER TO LOWER THE TOTAL HEAT LOSS FACTOR AS MUCH AS POSSIBLE.

FIRST OF ALL, THE ABSORBER SURFACE IS REDUCED BY THE USE OF A CONCENTRATING DEVICE. THE CONCENTRATION FACTOR HAS TO BE LOW, OTHERWISE THE ACCEPTANCE ANGLE IS TOO NARROW AND DIFFUSE RADIATION CANNOT BE COLLECTED.
OWING TO THIS FACT, A V-TROUGH SHAPED MIRROR IS CHOSEN.
THIS PARTICULAR SHAPE IS ALSO WELL ADAPTED TO BE USED AS SUPPORTS FOR THE GLASS COVER.
AN ILLUSTRATION OF THE DESIGN IS GIVEN PAGE 65

RADIATION LOSSES & SELECTIVE COATINGS

AT NORMAL OPERATING TEMPERATURES (T= 100-150 C), THE RADIATION REPRESENTENTS THE MOST IMPORTANT PART OF THE HEAT LOSSES, AND DOMINATES THE CONDUCTION LOSSES EVEN AT VERY LOW EMITTANCE.

THREE SELECTIVE COATINGS HAVE BEEN INVESTIGATED WITH RESPECT TO THEIR EMITTANCE, LIFETIME, THERMAL STABILITY AND COST PRICE.
THEY ARE :

* BLACK CHROMIUM * TINOXIDE * COBALTOXIDE

THERMAL STABILITY AND LIFETIME HAVE BEEN STUDIED AT NORMAL RUNNING TEMPERATURE (150 C) AND STAGNATION TEMPERATURE (300 C), IN VACUUM AND IN AIR.
IT IS FOUND THAT THE COBALTOXIDE LAYER ON A NICKEL SURFACE HAS THE BETTER THERMAL STABILITY, AS SHOWN HEREUNDER :

	AIR				VACUUM			
	150 C		300 C		150 C		300 C	
	α	ε	α	ε	α	ε	α	ε
AT START	.89	.07	.87	.07	.89	.07	.89	.07
2 MONTHS	.89	.07	.86	.08	.89	.07	.89	.08
6 MONTHS	.89	.07	.83	.09	.89	.07	.89	.08

CONVECTION LOSSES & PRESSURE

A THEORETICAL AND EXPERIMENTAL INVESTIGATION HAS BEEN UNDERTAKEN ABOUT THE DEPENDANCE OF CONVECTION LOSSES VERSUS INSIDE PRESSURE.
THE RESULTS SHOW THAT A PRESSURE OF 4000 Pa IS SUFFICIENT TO MAKE CONVECTION LOSSES ALMOST NEGLIGIBLE.
MOREOVER, WORKING WITH THAT PRESSURE LEVEL SHOULD NOT LEAD TO TOO SEVERE SEALING REQUIREMENTS (SEE BELOW).

CONDUCTION LOSSES

CONDUCTION LOSSES CAN BE DECREASED BY USING OTHER GAS THAN AIR INSIDE THE COLLECTOR. PURE XENON HAS A CONDUCTIVITY 3 TIMES LOWER THAN AIR. ALSO CCl4 OR R113 CAN BE USED.

CONSTRUCTION OF A PROTOTYPE

EVACUATION OF THE COLLECTOR HOUSING REQUIRES SPECIAL PRECAUTION WITH RESPECT TO STRENGTH AND SEALING.
BOTH ASPECTS HAVE BEEN CAREFULLY TAKEN INTO ACCOUNT IN THE DESIGN AND BUILDING OF A PROTOTYPE.

THE COVER IS SUPPORTED BY THE V-TROUGHS, SPACED FROM 200 mm; WHILE THE SEALING TECHNIQUE IS THE SAME AS THAT UTILIZED IN DOUBLE-GLAZING UNITS (WITH THE COMBINATION BUTYL-POLYSULFIDE). THIS SEALING SYSTEM SATISFIES BOTH LIFETIME AND LEAKAGE CRITERIA.

FINALLY, TINOXIDE IS SELECTED AS COATING SURFACE (α=.92;ε=.15)

THE FIRST PROTOTYPE DISCUSSED HERE WAS AIMED AT THE VERIFICATION OF FEASABILITY, DURABILITY OF THE VACUUM, AND MEASUREMENT OF THE HEAT LOSS COEFFICIENT, WHICH WAS FOUND TO BE EQUAL TO 2 W/m2 C AT 90 C, DUE TO THE HIGH EMISSIVITY OF THE COATING. IT SEEMS TO BE POSSIBLE TO CONSTRUCT A COLLECTOR WITH A K-VALUE OF ABOUT 1.0.

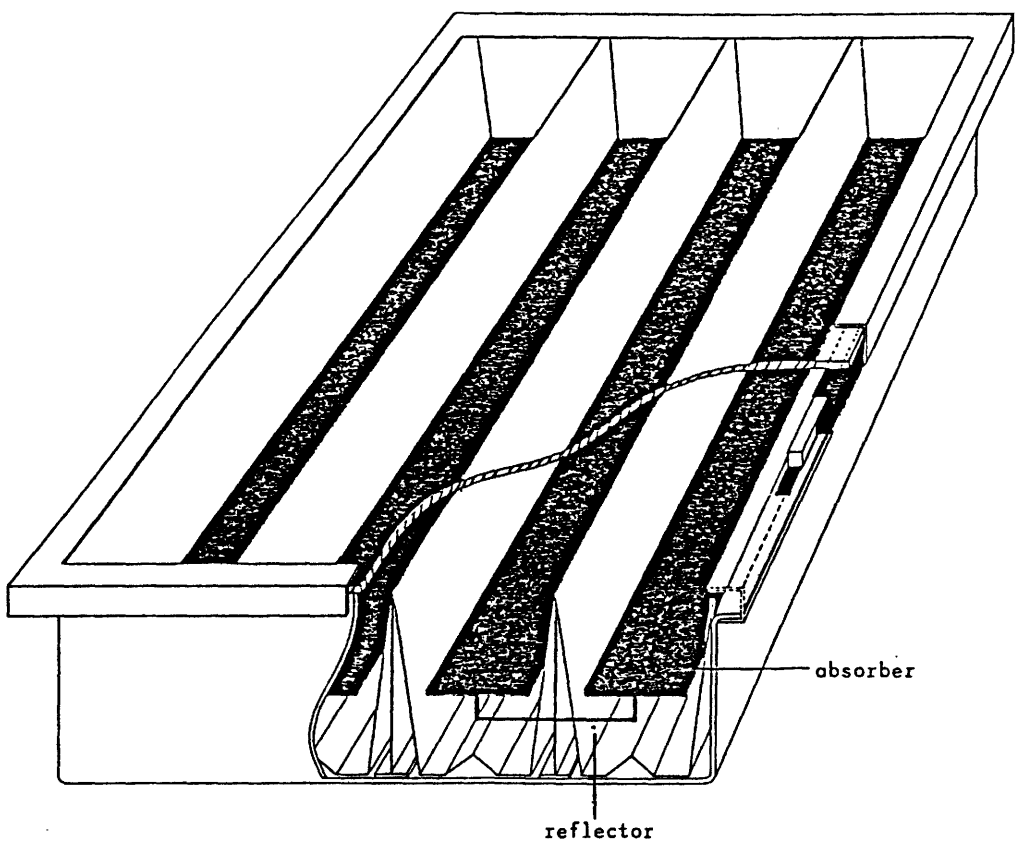
CONCLUSION

THE USE OF TROUGH-SHAPED CONCENTRATORS MAKES IT POSSIBLE TO EVACUATE FLAT PLATE COLLECTORS.
THE OPTIMUM CONCENTRATION RATIO OF 1.6 IS SUITABLE FOR A STATIONARY FLAT PLATE COLLECTOR.

THE SEALING TECHNIQUE UTILIZED IS PROVEN TO PROVIDE LIFETIMES OF +/- 8 YEARS, WHILE KEEPING A REDUCED CONVECTION HEAT LOSS.

A MINIMUM HEAT LOSS FACTOR OF 1 W/m2 C COULD BE ACHIEVED WITH A HIGH QUALITY SELECTIVE COATING (ε =.10) COMBINED WITH A LOW CONDUCTIVE GAS.

Fig. 9 Design main aspects



Dimensions : 165 x 85 x 13 cm
Weight : approx. 50 kg

TITLE : STUDY AND CONSTRUCTION OF
FLAT PLATE COLLECTOR CAPABLE OF 80 TO 150 C

CONTRACT NR : 529-78-7-ESF

ORGANIZATION : SOCIETE BERTIN & Cie
B.P. 3
F - 78370 PLAISIR

PROJECT HEAD : G. DAHAN

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AIM OF THE PROJECT

THE MAXIMUM WORKING TEMPERATURE OF CLASSICAL FLAT PLATE COLLECTORS WITH SELECTIVE COATING IS LIMITED TO ABOUT 70 C.
IF HIGHER TEMPERATURES HAVE TO BE ACHIEVED, THE CONVECTION AND CONDUCTION LOSSES MUST BE ELIMINATED.
THE AIM OF THIS RESEARCH IS TO DEVELOP A NEW TYPE OF EVACUATED FLAT PLATE COLLECTOR, BASED ON THE TELEVISION-TUBES TECHNOLOGY.

PRELIMINARY STUDIES

A GENERAL STUDY OF THE PERFORMANCES OF EVACUATED COLLECTORS HAS BEEN UNDERTAKEN. IT IS SHOWN THAT THE CONVECTION LOSSES CAN BE SUPPRESSED FOR AN INTERNAL PRESSURE OF ABOUT 10 Torr. TO ELIMINATE CONDUCTION LOSSES, WHICH REMAIN IMPORTANT AT HIGH TEMPERATURES, THE PRESSURE MUST BE LOWER THAN 1.E-3 Torr.

THREE TECHNOLOGICAL SOLUTIONS HAVE BEEN ENVISAGED :

* A TUBULAR COLLECTOR. THIS WELL-KNOWN SOLUTION HAS BEEN IMPROVED BY USING RADIATION SHIELDINGS ;
* A COLLECTOR WITH A FLAT ENVELOPE MADE OF GLASS AND METAL.
* A COLLECTOR WITH AN ALL-GLASS ENVELOPE. (TV-TUBE TECHNOLOGY).

AFTER A CAREFUL STUDY, THE LAST PROPOSITION WAS FOUND TO BE THE BEST, WITH RESPECT (ESSENTIALLY) TO ITS HIGHER SOLIDITY, ITS ABILITY TO SUPPORT VACUUM FOR MANY YEARS (A PRESSURE OF 5.E-4 Torr SHOULD BE MAINTAINED DURING 30 YEARS), AND LOWER LOSSES IN CONNECTIONS.

FURTHERMORE, A VERY LOW COST MAY BE EXPECTED FROM THE FACT THAT TV-TUBES ARE MANUFACTURED BY MILLIONS. A MASS PRODUCTION OF SUCH COLLECTORS COULD LEAD TO A COST SIMILAR TO THAT OF CONVENTIONAL FLAT PLATE COLLECTORS.
THE MAIN DISADVANTAGES ARE THE HIGH WEIGHT (100 kg/m2) AND THE FRAGILITY OF GLASS-METAL SEALING AT THE BACK.

DESCRIPTION OF THE BERTIN TV-TUBE COLLECTOR

THE GLASS ENVELOPE IS MADE OF TWO PARTS ; THE FRONT GLASS AND THE BACK CONICAL ENVELOPE ARE "WELDED" WITH GLASS PASTE.
FOR THE ABSORBER, A COPPER PLATE COATED WITH BLACK CHROMIUM IS USED. THE BACK SIDE OF THIS PLATE IS INSULATED WITH TWO ALUMINIUM SHIELDS WITH L-SHAPED EDGES, IN ORDER TO LOWER LATERAL RADIATION LOSSES.

THE ABSORBER AND SHIELDS ARE SUPPORTED IN THE TV-TUBE BY THE MEANS OF EXISTING BUILT-IN PINS.
THE INLET AND OUTLET TUBES ARE BRAZED TO A METALLIC PART, WHICH IS SEALED WITH THE BOTTOM OF THE GLASS TUBE.

THE MAIN MANUFACTURING STEPS ARE AS FOLLOWS :

* FASHIONING OF THE CIRCUIT
* BRAZING OF TUBE ON THE ABSORBER
* CLEANING OF THE ABSORBER
* DEPOSITION OF A SELECTIVE COATING
* FASHIONING OF ALUMINIUM SHIELDINGS
* MOUNTING OF ABSORBER AND SHIELDINGS IN THE ENVELOPE
* SEALING OF THE GLASS ENVELOPE
* GLASS-METAL SEALING FOR THE TUBES
* SIMULTANEOUS EVACUATING AND HEATING (350 C)
* FITTING OF THE ANTI-IMPLOSION BELT

A DEEP VACUUM OF 1.E-5 Torr IS OBTAINED BY THE USE OF A GETTER.

PREDICTION OF PERFORMANCES

THE REPORT PRESENTS THE DETAILED CALCULATIONS OF THE THERMAL LOSSES OF THE COLLECTOR, AND THE PREDICTED EFFICIENCIES ARE DEDUCED : FOR AN INCIDENT RADIATION OF 800 W/m2 AND AN AMBIENT TEMPERATURE OF 15 C THE EFFICIENCY IS 65 % AT 80 C
51 % AT 120 C
39 % AT 150 C.

EXPERIMENTAL INVESTIGATIONS

FIRST OF ALL, A VERIFICATION OF THE INFLUENCE OF THE PRESSURE OVER THE CONVECTION AND CONDUCTION LOSSES CONFIRMED THE PREDICTIONS.
ON THE OTHER HAND, IT HAS BEEN FOUND THAT CONDUCTION LOSSES ALONG THE SUPPORTS HAD BEEN OVERESTIMATED, AND THAT THE SELECTIVE COATING HAD NOT RESISTED TO THE HEATING PHASE OF THE MANUFACTURING : THE ABSORPTION COEFFICIENT LOOSED 14 POINTS AND THE EMISSIVITY IS DECREASED BY 8 POINTS.
THE OPTICAL EFFICIENCY, WHICH WAS EXPECTED TO BE .80, WAS FOUND TO BE IN FACT .67.

A COMPARISON BETWEEN THE PREDICTED AND MEASURED EFFICIENCIES SHOWS THAT THE EXPERIMENTAL EFFICIENCY IS 7 % LOWER THAT THE PREDICTED FIGURE, IN THE RANGE 80 - 120 C, FOR AN IRRADIATION OF 800 W/m2. UNDER 500 W/m2, THE DISCREPANCY IS ONLY 3 %.

CONCLUSION

THE REALIZATION OF A SERIES OF EVACUATED COLLECTORS HAS DEMONSTRATED THEIR TECHNOLOGICAL FEASIBILITY.
THE PRACTICAL INVESTIGATIONS HAVE CONFIRMED 1.- THE ABILITY OF THE COLLECTOR TO KEEP A DEEP VACUUM FOR LONG PERIODS AND
2.- THE LOW LEVEL OF HEAT LOSSES.

A ROUGH ESTIMATION LEADS TO A COST OF 1500 FF/m2 (SEPT. 79), WHICH IS TWO OR THREE TIMES THE COST OF A CONVENTIONAL SELECTIVE FLAT PLATE COLLECTOR. A MORE ACCURATE COST STUDY HAS STILL TO BE DONE.

TITLE : STUDY OF THE SUPPORTING AND INTEGRATION OF THE BERTIN'S EVACUATED TV-TUBE COLLECTOR

CONTRACT NR : ESA-C-018-F

ORGANIZATION : SOCIETE BERTIN & CIE
B.P. 3
F - 78370 PLAISIR

PROJECT HEAD : GROSSIN

AIM OF THE PROJECT

THIS STUDY DEALS WITH THE DESIGN OF A SUPPORTING DEVICE FOR THE TV-TUBE COLLECTOR DEVELOPED WITHIN THE FRAME OF C.E.C. CONTRACT NR 529-78-7-ESF.
IN A SECOND PART, A CALCULATION CODE IS PROPOSED FOR THE PREDICTION OF YEARLY AND MONTHLY SOLAR ENERGY THAT CAN BE COLLECTED BY THESE COLLECTORS.

SUPPORTING STRUCTURE

THE FOLLOWING ASPECTS HAVE TO BE CONSIDERED IN THE DESIGN OF THE SUPPORTING STRUCTURE :

* THE WEIGHT OF EACH COLLECTOR IS 25 KG;
* THE DEPTH IS IMPORTANT (MORE THAN 400 MM);
* THE TV-TUBE IS FRAGILE;
* THE PIPE-CONNECTIONS MUST BE CAREFULLY INSULATED.

MOREOVER, IT IS IMPORTANT THAT THE STRUCTURE COULD BE INTEGRATED EASILY IN THE FACADE OF A BUILDING.
THE FINAL DESIGN CONSISTS IN A STRUCTURE SUPPORTING FOUR COLLECTORS. THE CHEAPEST MATERIAL - ALTHOUGH HEAVY - IS CONCRETE.
THIS STRUCTURE CAN BE EITHER DIRECTLY TAILED IN THE BUILDING OR SET ON ANOTHER CONCRETE SUPPORT. THE PHOTOGRAPH, BELOW, GIVES AN IDEA OF THE SOLUTION.

THE THERMAL INSULATION OF THE PIPING HAS AN OUTER DIAMETER OF 150 MM (THE PIPE IS A 1/4").

AN ARRAY OF 25 SUPPORTING STRUCTURES (100 COLLECTORS) IS NOW BEING INSTALLED IN A FIELD, FOR EXPERIMENTATION. NO MAJOR PROBLEM HAS BEEN ENCOUNTERED FOR THE MOMENT.

CALCULATION OF THE SOLAR ENERGY COLLECTED

THE CALCULATION IS MADE WITH THE WEATHER DATA OF TRAPPES (NEAR PARIS) AND CARPENTRAS (SOUTH OF FRANCE).
THE FOLLOWING TABLE GIVES THE YEARLY SOLAR ENERGY COLLECTED BY THE BERTIN COLLECTOR, IN COMPARISON WITH TWO CLASSICAL COLLECTORS, NON-SELECTIVE AND SELECTIVE ("CCNS" , "CCS", RESPECTIVELY)

TITLE : SOLAR ENERGY APPLICATIONS FOR DWELLINGS
MODELLING AND SIMULATION PART

CONTRACT : 228-77-DK

ORGANIZATION : THERMAL INSULATION LABORATORY
TECHNICAL UNIVERSITY OF DENMARK
DK - 2800 LYNGBY

PROJECT HEAD : OVE JORGENSEN

AIM OF THE PROJECT

THE OBJECTIVE OF THIS WORK WAS TO PERFORM A COMMON EVALUATION OF MATHEMATICAL SIMULATION AND CALCULATIONS METHODS FOR THE PREDICTION OF THE THERMAL PERFORMANCE OF SOLAR ENERGY SYSTEMS AND THEREBY ENLIGHTEN THE EFFECT OF DIFFERENT MODELLING ASSUMPTIONS AND PRODUCE GUIDELINES FOR THE CONSTRUCTION OF SIMPLIFIED METHODS.

THE COMPUTER PROGRAMMES OF A NUMBER OF PARTICIPANTS HAVE BEEN COMPARED ON THE BASIS OF YEARLY, MONTHLY AND HOURLY TABLES; IN ADDITION, A PARAMETER SENSIVITY ANALYSIS HAVE BEEN DONE.
THE PARTICIPANTS TO THIS STUDY WERE :

* A.T.R.A.C. (BELGIUM)
* KATHOLIEKE UNIVERSITEIT LEUVEN (BELGIUM)
* TECHNICAL UNIVERSITY OF DENMARK (DENMARK)
* FRAUNHOFER GESELLSCHAFT (W. GERMANY)
* THE UNIVERSITY OF LEEDS (ENGLAND)
* UNIVERSITY COLLEGE CARDIFF (ENGLAND)
* OPEN UNIVERSITY, MILTON KEYNES (ENGLAND)
* STICHTINGEN BOUWCENTRUM EN RATIOBOUW (HOLLAND)
* INSTITUTE FOR INDUSTRIAL RESEARCH AND STANDARD (IRELAND)

THREE DIFFERENT SYSTEMS WERE SET UP TO BE CALCULATED BY THE CONTRACTORS OF THIS PROJECT :

* A COMBINED SYSTEM FOR BOTH HOUSE HEATING AND HOT WATER
* A PURE HOUSE HEATING SYSTEM
* A PURE DOMESTIC HOT WATER SYSTEM.

FIVE PROGRAMMES HAVE BEEN USED TO CALCULATE ALL THREE SOLAR HEATING SYSTEMS; ONE TO CALCULATE THE TWO LAST; THE OTHER FIVE PROGRAMMES RAN ONLY FOR THE LAST CASE.

THE SAME TECHNICAL AND WEATHER DATA WERE INPUT IN ALL THE PROGRAMMES.

SIMULATION MODEL ASSUMPTIONS

CONCLUSIONS ON THE EFFECT OF USING CERTAIN ASSUMPTIONS IN THE MODELS CAN ONLY BE DRAWN WITH RESPECT TO THE PURPOSE OF THE MODEL. FURTHERMORE, MOST OF THE ASSUMPTIONS ARE CHARACTERISED BY HAVING A RELATIVELY LARGE EFFECT ON A SHORT TERM BASIS (HOURS) BUT ALMOST NO EFFECT ON A MONTHLY OR YEARLY BASIS.

THE LONG TERM RESULTS COMPARED IN THE REPORT LEAD TO THE FOLLOWING COMMENTS WITH REGARD TO THE SIMPLIFYING ASSUMPTIONS:

* THE EFFECT OF MODELLING THE COLLECTOR WITHOUT A THERMAL CAPACITY SEEMS TO RESULT IN A SMALL OVERPREDICTION OF THE PERFORMANCE OF SMALL SYSTEMS;
* THE USE OF A CONSTANT $\alpha\tau$ VALUE (MAXIMUM EFFICIENCY OF THE COLLECTOR) AND/OR UL VALUE (COLLECTOR LOSS FUNCTION) HAS NO EFFECT;
* MODELLING OF THE START UP CONTROL WITH FLOW IN THE COLLECTOR HAS NON-NEGLIGIBLE EFFECT ON THE PREDICTED SOLAR SUPPLY;
* NOTHING CAN BE CONCLUDED WITH RESPECT TO MODELLING THE SYSTEM WITH OR WITHOUT HEAT EXCHANGER, BECAUSE THE ONE USED IN THIS STUDY WAS FAR TOO OVERSIZED;
* THERE IS AN INDICATION THAT PIPING LOSSES SHOULD BE MODELLED WITH CARE.

SIMPLIFIED METHODS

THE TWO IRISH PROGRAMMES USE SIMPLIFIED METHODS.
NO FIRM CONCLUSIONS CAN BE DRAWN TO THE VALIDITY OF THESE, ALTHOUGH THEY SHOW GOOD AGREEMENT WITH THE SIMULATION MODELS BOTH ON YEARLY AND MONTHLY PREDICTIONS. HOWEVER, THE PERFORMANCE SENSIVITY TO CERTAIN PARAMETER VARIATION SHOULD BE FURTHER DEVELOPED.

CONCLUSION

ON THE BASIS OF THE WORK CARRIED OUT IN THIS PROJECT, IT CAN BE CONCLUDED THAT FOR CALCULATING YEARLY SOLAR SUPPLIES OF THE DIFFERENT SOLAR SYSTEMS CONSIDERED, ALL THE DIFFERENT ASSUMPTIONS TAKEN IN THE MODELS PRESENTED IN THE REPORT SEEM TO BE CORRECT AND DO NOT LEAD TO MISLEADING RESULTS.
BUT WHEN THE MODELLING IS PERFORMED FOR SPECIAL PURPOSES AND FOR DETAILED PERFORMANCE EVALUATIONS, SPECIAL CARE SHOULD BE TAKEN, PARTICULARLY TO CHOOSING THE RIGHT MODEL FOR THE GIVEN PURPOSE.

MOST PROGRAMS CAN BE SAID TO BE REASONABLY ACCURATE FOR PREDICTING THE YEARLY SOLAR CONTRIBUTION TO ANY NORMAL SOLAR HEATING SYSTEM, USING ANY SET OF WEATHER DATA. HOWEVER, ONLY THE MOST COMPLICATED MODELS CAN ACCURATELY CALCULATE THE HOURLY PERFORMANCES.

FOR WHAT CONCERNS TRANSFERABILITY AND USEFULNESS, VERY FEW OF THE COMPUTER PROGRAMMES CAN PRETEND TO MEET THESE REQUIREMENTS.

NOTE : THE ANNEX TO THE MAIN REPORT GIVES THE DETAILED DESCRIPTION OF THE DIFFERENT SIMULATION CODES.

TITLE : ABSORPTION REFRIGERATION MACHINE
DRIVEN BY SOLAR HEAT

CONTRACT NR : 530-78-1-ESN

ORGANIZATION : DELFT UNIVERSITY OF TECHNOLOGY
JULIANALAAN 134
NL - 2628 DELFT

PROJECT HEAD : C. KEIZER

PUBLISHED AS MICROFICHE REPORT EUR 6748 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE WORK UNDERTAKEN IN THE FRAME OF THIS CONTRACT IS A PART OF A LARGER PROGRAMME DEALING WITH ABSORPTION COOLING MACHINES.

THE AIM OF THE PRESENT RESEARCH IS TO DEVELOP A MATHEMATICAL MODEL OF A SINGLE STAGE AND TWO STAGES ABSORPTION REFRIGERATING PROCESS IN WHICH SOLAR COLLECTORS CHARACTERISTICS AND WEATHER DATA ARE IMPLICATED.

THERMODYNAMICAL PROPERTIES OF THE MIXTURE

THE THERMODYNAMICAL PROPERTIES OF AMMONIA-WATER MIXTURE HAVE BEEN WRITTEN IN AN ANALYTICAL FORM, ACCORDING TO SCHULZ.
THE EQUATIONS ARE BASED ON THE CONCEPT OF FREE ENTHALPY OF THE BINARY MIXTURE, AND ARE VALID IN THE TEMPERATURE AND PRESSURE RANGES CONSIDERED IN THIS WORK.

THE SUBROUTINES USED IN THE CALCULATIONS OF THERMODYNAMIC PROPERTIES ARE PRESENTED IN THE REPORT.

THE ABSORPTION PROCESS

THE SINGLE STAGE AND TWO STAGES ABSORPTION MACHINES ARE DESCRIBED AND THE COMPLETE SET OF EQUATIONS OF HEAT AND MASS BALANCES IS GIVEN FOR EACH COMPONENT OF THE PROCESS.

THEORETICAL RELATIONSHIPS (IN A LINEAR FORM) ARE STATED FOR THE DESCRIPTION OF THE BEHAVIOUR OF SOLAR COLLECTORS.
FIVE TYPES OF COLLECTORS ARE CONSIDERED :
FLAT PLATE, SINGLE GLAZED / FLAT PLATE, DOUBLE GLAZED / FLAT PLATE, SELECTIVE, SINGLE AND DOUBLE GLAZED / HIGH PERFORMANCE COLLECTOR. IN THE MODEL, A RADIATION FLUX OF 550 W/m2 AND AN AMBIENT TEMPERATURE OF 30 C ARE CHOOSEN.

THE ASSUMPTION IS MADE IN THE COMPUTER MODEL, THAT THE CONCENTRATION OF AMMONIA IN THE MIXTURE LEAVING THE DEFLEGMATOR IS 0.999 .

RESULTS OF THE CALCULATIONS

THE SIMULATION PROGRAMMES HAVE BEEN RUNNING WITH THE FOLLOWING DATA : * TEMPERATURE LEVELS : -5 C ; 30 C ; 85 TO 140 C ;
* RADIATION FLUXES : 400 TO 600 W/m2.

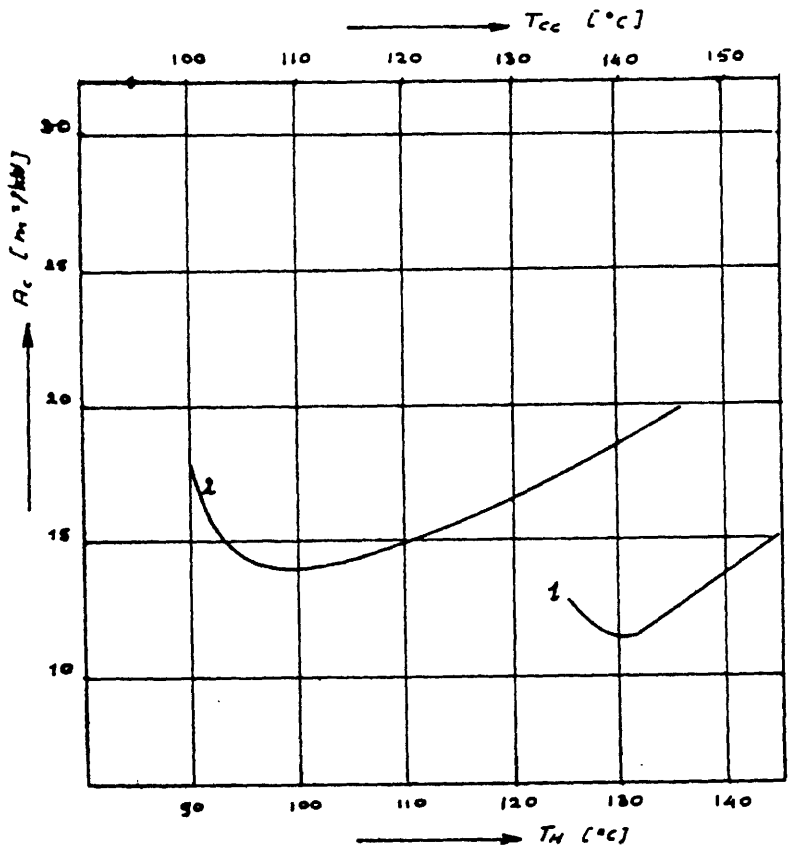
IT IS FOUND THAT ONLY SELECTIVE DOUBLE GLAZED COLLECTORS OR HIGH PERFORMANCE COLLECTORS ARE ABLE TO OPERATE THE PROCESS, THE OTHER SOLAR COLLECTORS HAVING TOO LOW EFFICIENCIES IN THE REQUIRED TEMPERATURE RANGE.

THE PARTIAL EFFICIENCIES OF THE COMPONENTS OF THE PROCESS HAVE BEEN SEPARATELY CONSIDERED AS PARAMETERS, IN ORDER TO EVALUATE THEIR INFLUENCE OVER THE C.O.P. (WHILE VARYING ONE EFFICIENCY, THE OTHERS ARE CONSIDERED TO BE EQUAL TO 100 %).

THE INFLUENCE OF THE GENERATOR EFFICIENCY IS MORE IMPORTANT :
* WHEN THE CONDENSER TEMPERATURE IS HIGH ;
* WHEN THE GENERATOR TEMPERATURE IS HIGH ;

THE C.O.P. IS MORE AFFECTED BY THE GENERATOR EFFICIENCY, AT HIGH HOT SOURCE TEMPERATURES ; AT LOWER GENERATOR TEMPERATURES, THE INFLUENCE OF THE ABSORBER EFFICIENCY PREDOMINATES.

THE FIGURE ON THE NEXT PAGE SHOWS THE REQUIRED AREA OF HIGH PERFORMANCE COLLECTORS, FOR A SINGLE AND A TWO STAGES SOLAR ABSORPTION REFRIGERATION SYSTEM (AMBIENT TEMPERATURE : 30 C ; EVAPORATION TEMPERATURE : -5 C ; RADIATION FLUX : 550 W/m2 ; COOLING POWER : 1 kW) AS A FUNCTION OF THE HOT SOURCE TEMPERATURE.
SELECTIVE DOUBLE GLAZED COLLECTORS ARE NOT SUITABLE FOR USE IN A SINGLE STAGE SYSTEM, THE REQUIRED TEMPERATURES BEING TOO HIGH.



CONCLUSION

THE COOLING TEMPERATURE DETERMINES THE EVAPORATOR TEMPERATURE ASWELL AS THE GENERATOR TEMPERATURE. AS FAR AS AIR-COOLING IS CONCERNED, SOLAR ABSORPTION SYSTEMS CANNOT REACH LOW COOLING TEMPERATURES AND HIGH PERFORMANCE COLLECTORS ARE REQUIRED.

THE REQUIRED AVERAGE SOLAR RADIATION MUST BE GREATER THAN 400 W/m2. THIS FIGURE IS OPTIMISTIC FOR CENTRAL EUROPE. ON THE OTHER HAND, THE AMBIENT TEMPERATURE OF TROPICAL COUNTRIES LEADS TO HIGH CONDENSER AND ABSORBER TEMPERATURES, WHICH LOWER THE C.O.P..

IN ANY CASES, SOLAR ABSORPTION PROCESSES NEED THE DEVELOPMENT OF EFFICIENT GENERATORS AND ABSORBERS, WHICH HAS STILL TO BE DONE.

TITLE : DEVELOPMENT OF AN AUTONOMOUS FREE PISTON REFRIGERATING UNIT DRIVEN BY RANKINE CYCLE

CONTRACT NR : 528-78-1-ESB

ORGANIZATION : UNIVERSITE LIBRE DE BRUXELLES
INSTITUT DE MECANIQUE APPLIQUEE
AVENUE F.D. ROOSEVELT 50
B - 1050 BRUXELLES

PROJECT HEAD : A. JAUMOTTE - J. BOUGARD

PUBLISHED AS MICROFICHE REPORT EUR 6786 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE RESEARCH DEALS WITH A FREE PISTON REFRIGERATING MACHINE SUPPLYING A NET OUTPUT OF 3 KW AT 10 C, WITH 25 C AMBIENT, DRIVEN BY SOLAR HEAT AT LOW TEMPERATURE : 70 C.

THE DRIVING CYCLE AND THE FRIGORIFIC ONE HAVE A COMMON CONDENSER, FOR SIMPLIFICATION AND ECONOMIC IMPERATIVES.

THERMODYNAMIC CYCLE

A CAREFUL EXAMINATON OF THE WORKING MEDIA LED TO A CHOICE BETWEEN TWO POSSIBLE FLUIDS : R12 OR R114.
THE THERMODYNAMIC CYCLE AND HEAT EXCHANGERS HAVE BEEN OPTIMIZED BY A COMPUTER ANALYSIS, TAKING THE FOLLOWING PARAMETERS INTO ACCOUNT :

* TEMPERATURES OF THE HEAT SOURCES
* TEMPERATURE DIFFERENCES IN THE HEAT EXCHANGERS
* PRESSURE DROPS THROUGH THE HEAT EXCHANGERS
* ISENTROPIC EFFICIENCIES OF THE MACHINES
* HEAT FLUXES IN THE BOILER - CONDENSER - EVAPORATOR
* EFFICIENCIES AND POWERS OF THE FANS
* EFFICIENCY OF A BUILT-IN ELECTRICAL GENERATOR.

AT THE DESIGN POINT, THE CALCULATIONS SHOWED AN OVERALL C.O.P. OF .27 (WITH R12) AND .25 (WITH R114).
THE VOLUMETRIC FRIGORIFIC CAPACITIES ARE RESPECTIVELY 2812 AND 949 kJ/m3. THESE FIGURES INDICATE ALREADY THE DIFFERENCES IN MACHINE SIZES : A MUCH SMALLER MACHINE WILL BE OBTAINED IF THE WORKING MEDIUM IS R12 THAN IF R114 IS USED.

FREE PISTON MACHINE

A VERY ATTRACTIVE DESIGN HAS BEEN FOUND, WHICH MAKES USE OF

A SINGLE RECIPROCATING FREE PISTON, ENCLOSED IN AN HERMETICALLY SEALED CYLINDER (PATENT APPLICATIONS HAVE BEEN FILED IN DIFFERENT COUNTRIES).

ALL MECHANICAL FUNCTIONS - MOTOR, COMPRESSOR, PUMP - ARE PERFORMED BY THIS SINGLE MOVING PART, THANKS TO ITS PARTICULAR SHAPE (SEE THE ILLUSTRATION PAGE 84).

TWO ADDITIONAL COMPUTER PROGRAMMES HAVE BEEN SET UP, WHICH CAN SIZE THE MACHINE AND PREDICT THE PERFORMANCES AT OFF-DESIGN CONDITIONS.
THESE TWO PROGRAMMES ARE BASED ON THE INTERACTION OF THERMODYNAMIC CONCEPTS AND ANALYSIS OF THE DYNAMIC BEHAVIOUR OF THE FREE PISTON.

PREDICTED PERFORMANCES

THE COOLING OUTPUT AND C.O.P. ARE PLOTTED PAGE 84 .
THIS GRAPH SHOWS THE EXCELLENT BEHAVIOUR OF THE MACHINE, EVEN WITH LOW TEMPERATURE HEAT.

THIS EASE OF OPERATION AT PART LOAD CAN BE EXPLAINED BY THE DYNAMIC BEHAVIOUR OF THE FREE PISTON. IN FACT, ITS STROKE ADAPTS ITSELF NATURALLY TO THE LOAD, AND MAINTAINS A QUASI-CONSTANT OSCILLATION FREQUENCY.

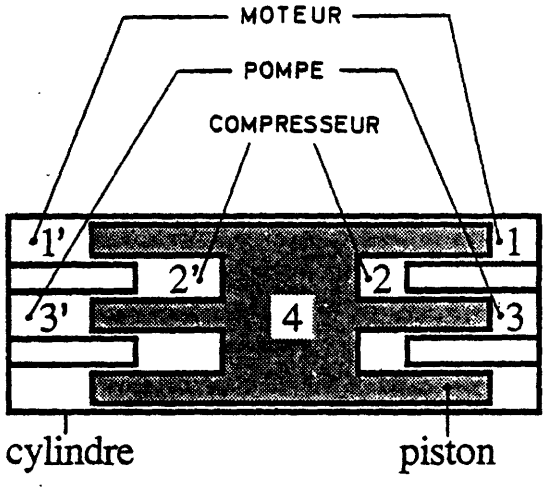
EXPERIMENTAL INVESTIGATIONS

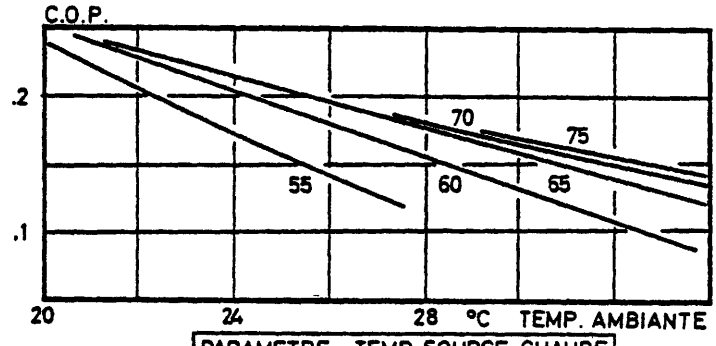
A FULL SCALE PROTOTYPE AND A TEST RIG HAVE BEEN BUILT.
IN ORDER TO VERIFY THE DYNAMIC BEHAVIOUR OF THE MACHINE, A FIRST ROUND OF TESTS HAVE BEEN CARRIED OUT WITH COMPRESSED AIR AS WORKING FLUID. THE RESULTS SHOW THAT THE MACHINE ACTUALLY WORKS, BUT SOME PROBLEMS ARE ENCOUNTERED WITH THE DISTRIBUTION DEVICE.

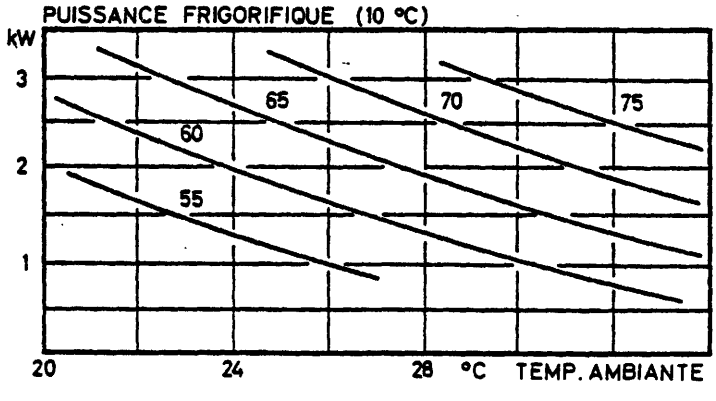
CONCLUSION

THE PROPOSED MACHINE SEEMS TO SOLVE IN AN ATTRACTIVE CONCRETE FORM, THE INTEGRATION IN A SINGLE CARTER OF A DRIVING THERMAL ENGINE AND A FRIGORIFIC COMPRESSOR, USING TWO COUPLED RANKINE CYCLES.

THIS COMBINATION HAS THE GREAT ADVANTAGE THAT IT CAN WORK WITH HOT TEMPERATURES MUCH LOWER THAN EARLIER : 50 TO 70 C CAN BE ACHIEVED - WITH GOOD EFFICIENCY - BY CLASSICAL COMMERCIAL FLAT PLATE COLLECTORS.







TITLE : INTERMITTENT CYCLES USING
SOLID ADSORBENTS FOR SOLAR COOLING

CONTRACT NR : 524-78-1-ESF

ORGANIZATION : C. N. R. S.
QUAI ANATOLE FRANCE 15
F - 75700 PARIS

PROJECT HEAD : F. MEUNIER

PUBLISHED AS MICROFICHE REPORT EUR 7708 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE AIM OF THIS PROJECT IS TO DEVELOP AN AUTONOMOUS SOLAR COOLING UNIT USING ADSORPTION PROPERTIES OF CERTAIN SOLID MATERIALS.

THE FOLLOWING ADSORBENT/FRIGORIGEN COUPLES ARE STUDIED :

* ZEOLITHE 13X/WATER FOR AIR CONDITIONING PURPOSE
* ZEOLITHE 13X/METHANOL FOR ICE-PRODUCTION

WORKING PRINCIPLE

ONLY SINGLE EFFECT CYCLES, WITHOUT HEAT REGENERATION ARE CONSIDERED HERE. SUCH CYCLES PRODUCE THEIR COOLING EFFECT DURING THE NIGHT AND NEED SOLAR ENERGY TO REGENERATE THE ADSORBENT DURING THE DAY.

THE MACHINE IS ESSENTIALLY COMPOSED OF AN EVAPORATOR, A CONDENSER AND A SOLAR COLLECTOR FILLED WITH ZEOLITHE, IN WHICH REGENERATION OR ADSORPTION TAKE PLACE.
THE ZEOLITHE COMPARTMENT IS HERMETICALLY SEALED, ALLOWING THE COLLECTOR TO WORK AS A WATER HEATER WHEN NO COOLING EFFECT IS NEEDED - DURING WINTER PERIOD F.I..
NON-RETURN VALVES ISOLATE THE DIFFERENT LOOPS OF THE CIRCUIT DURING THE PHASES OF OPERATION.

USING THE COUPLE Z 13X/WATER, THE TYPICAL WORKING TEMPERATURES ARE AS FOLLOWS :

* EVAPORATOR 5 C
* CONDENSER 50 C
* ADSORBENT 50 - 30 C
* REGENERATION 130 C

THE EQUILIBRIUM DIAGRAMS GIVING THE MASS OF ADSORBED WATER HAVE BEEN DETERMINED EXPERIMENTALLY BY THERMOGRAVIMETRY.

ADSORPTION CHARACTERISTICS OF ZEOLITHES

IN ORDER TO MAKE A SELECTION OF SUITABLE ADSORBENT/FRIGORIGEN COUPLES, THE ISOTHERMS AND ISOSTERIC HEAT OF ADSORPTION HAVE BEEN MEASURED WITH A "MAC BAIN" THERMOBALANCE AND A "MCB" CALORIMETER.

THE FOLLOWING COUPLES ARE INVESTIGATED :

* Z 13X (POWDER) / WATER
* Z 4A / WATER
* Z 13X (IN GRAINS) / WATER
* Z 13X (IN GRAINS) / METHANOL
* Z 13X (POWDER) / METHANOL.

A SPECIALLY DESIGNED APPARATUS HAS BEEN USED TO STUDY THE KINETICS OF ADSORPTION OF THE PAIR Z 13X / METHANOL.

COMPUTER SIMULATION PROGRAMME

THE COMPARISON BETWEEN THE IDEAL C.O.P.'S OF SYSTEMS USING DIFFERENT COUPLES HAS BEEN CARRIED OUT BY A COMPUTER ANALYSIS. IT APPEARS THAT COUPLES WORKING WITH ZEOLITHE ARE NOT RIVAL BUT COMPLEMENTARY TO OTHERS - SUCH AS LiBr/WATER OR ALUMINA/WATER - AND IN FACT COVER THE SPECIFIC AREA PREVIOUSLY MENTIONED.

DEMONSTRATION UNIT USING Z 13X / METHANOL

PRIOR TO ANY OTHER WORK, A SPECIAL TEST RIG HAS BEEN BUILT UP IN ORDER TO GET MORE INFORMATION ABOUT THE BEHAVIOUR OF THE ZEOLITHE-FILLED SOLAR COLLECTOR. THESE TESTS WERE CARRIED OUT AT C.E.A. - SUBCONTRACTING ORGANIZATION.

THE DEMONSTRATION UNIT COMPRISES A SINGLE-GLAZED FLAT PLATE COLLECTOR COATED WITH BLACK CHROMIUM.

THE ABSORBER IS FILLED WITH 12 KG OF ZEOLITHE 13X, AND PLACED UNDER VACUUM.
THE REST OF THE INSTALLATION IS DESCRIBED PAGE 89 .

THE SYSTEM HAS BEEN INSTALLED OUTDOOR, TO BE STUDIED UNDER REAL CONDITIONS OF OPERATION.
ONLY ELEMENTARY MEASUREMENTS HAVE BEEN DONE, BUT PROVE THE ABILITY OF THE UNIT TO WORK PROPERLY.

AT THIS POINT OF THE RESEARCH, THE MAJOR PROBLEM ARISES FROM THE DIFFICULTY TO MAINTAIN A SUFFICIENT VACUUM IN THE ZEOLITHE COMPARTMENT.

DEMONSTRATION UNIT USING Z 13X / WATER

THIS INSTALLATION MAKES USE OF A COLLECTOR OF 1 m2, WHICH IS EXPOSED TO AN AVERAGE RADIATION FLUX OF 1000 WATT.

THE FOLLOWING FIGURES HAVE BEEN OBTAINED :

* TEMPERATURE IN THE CONDENSER 18 C
* REGENERATION TEMP. AFTER 4 HOURS 134 C
* OVERALL C.O.P. .14

NO FURTHER RESULTS ARE AVAILABLE AT THIS TIME.

CONCLUSION

THE MOST EXPENSIVE PART OF THIS TYPE OF COOLING UNIT IS OF COURSE THE SOLAR COLLECTOR - ACTUALLY , 1500 FF/m2.

HOWEVER, ICE PRODUCTION WITH THE COUPLE Z 13X / METHANOL SOLVES THE PROBLEM OF THE INTERMITTENT CYCLE OF OPERATION AND SEEMS TO BE VERY ATTRACTIVE.

FURTHER INVESTIGATIONS ARE BEING CARRIED OUT IN ORDER TO OPTIMIZE DIFFERENT PARAMETERS, AND WILL NORMALLY LEAD TO THE DESIGN OF TWO INDIVIDUAL REFRIGERATORS OF 150 AND 250 LITERS, AND ONE LARGE COLD STORAGE OF 20 m3 FOR THE CONSERVATION OF FRUITS AND VEGETABLES.

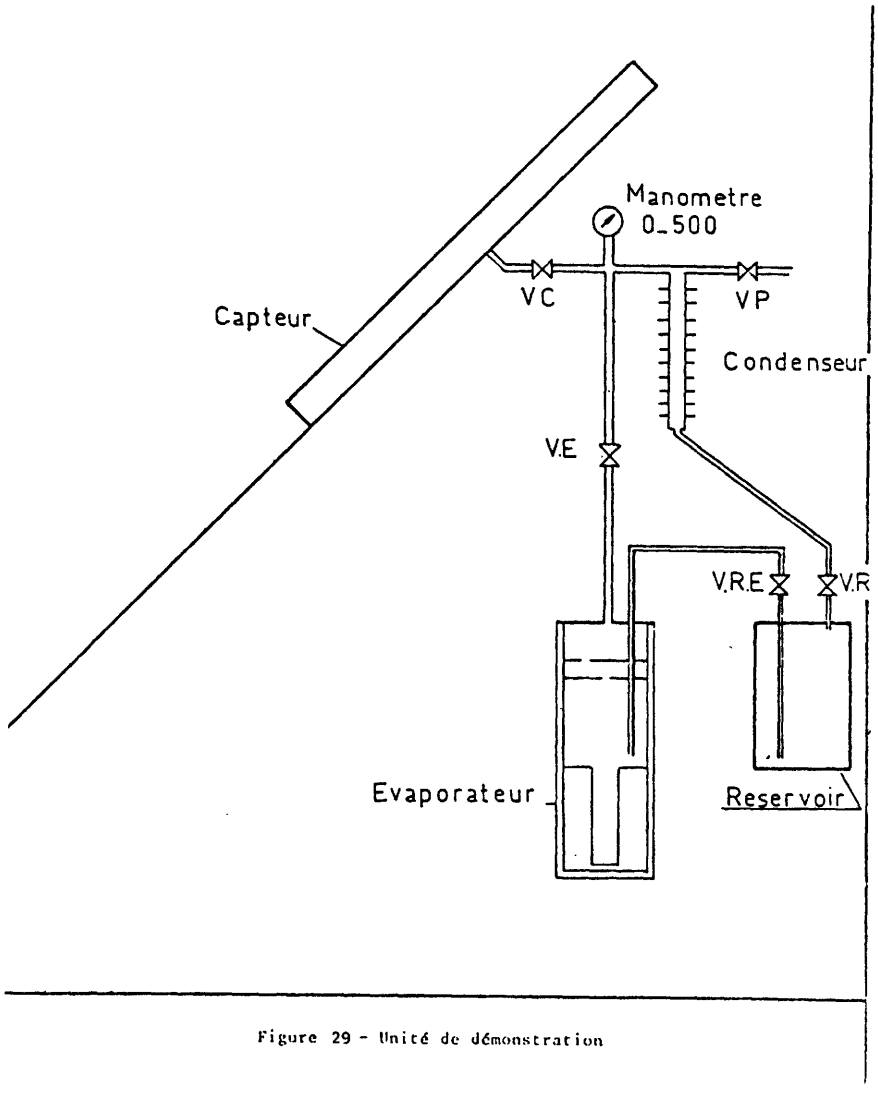


Figure 29 - Unité de démonstration

TITLE : STUDY AND EVALUATION OF THE LATENT COOLING POTENTIAL OF CHEMICAL DE-HUMIDIFIERS

CONTRACT NR : 527-78-1-ESUK

ORGANIZATION : OVE ARUP & PARTNERS
FITZROY STREET 13
GB - LONDON W1P 6BQ

PROJECT HEAD : J. CAMPBELL - D.M. LUSH

PUBLISHED AS MICROFICHE REPORT EUR 7711 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE RESEARCH IS CONCERNED WITH STUDIES TO ESTABLISH THE PRACTICAL APPLICATION OF SOLAR ENERGY TO THE FIELD OF LATENT COOLING BY DEHUMIDIFICATION.
THE STUDIES ARE TO BE DIRECTED TOWARDS THE PRODUCTION OF CRITERIA, SYSTEMS AND EVALUATION TECHNIQUES TO DETERMINE THE VIABILITY OF USING SOLAR ENERGY IN THIS FIELD.

SCOPE

THE SCOPE OF THE STUDY HAS BEEN LIMITED TO THE COMBINATION OF COMPARATIVELY LOW TEMPERATURE SOLAR ENERGY COLLECTION AND TWO TYPES OF DEHUMIDIFIER, THE LIQUID SPRAY TYPE AND THE ROTATING MATRIX TYPE.
THE BASIC DATA FOR THE CALCULATION OF THE DEHUMIDIFIER'S PERFORMANCE AT FULL AND PART LOAD HAVE BEEN OBTAINED FROM MANUFACTURERS OF COMMERCIAL DRYERS, AND EQUILIBRIUM PHASE DIAGRAMS.

THE FORM OF THE DEHUMIDIFYING LOAD CAUSED BY THE AIR CONDITIONING SYSTEM IN WHICH THE DEHUMIDIFIER IS FITTED HAS BEEN STUDIED FOR A SYSTEM WITH MODULATED RECIRCULATION.
IN SUCH A SYSTEM THE DEHUMIDIFIER CAN OFTEN PROVIDE ALL NECESSARY COOLING. THE PERFORMANCE IN OTHER SYSTEMS CAN BE DEDUCED SIMILARLY.

THE FORM OF THE REGENERATOR LOAD RESULTING FROM THE DEHUMIDIFYING LOAD HAS BEEN STUDIED AT VARYING WEATHER CONDITIONS FOR VARYING AVAILABLE HEAT SOURCE TEMPERATURES.

COEFFICIENTS OF PERFORMANCE

COEFFICIENTS OF PERFORMANCE ARE DEFINED FOR :

* THE EFFICIENCY OF THE DEHUMIDIFIER IN TERMS OF COOLING

POTENTIAL AND REGENERATOR ENERGY CONSUMPTION (TYPICAL VALUES ARE 0.4 TO 0.65) ;

* THE EFFICIENCY OF THE DEHUMIDIFIER AS AN ENERGY SAVING DEVICE IN THE TOTAL AIR CONDITIONING SYSTEM (TYPICAL VALUES ARE 0.5 TO 0.8).

THE COEFFICIENTS OF PERFORMANCE ARE CALCULATED FOR VARIOUS REGENERATION TEMPERATURES, WITH INDICATIONS OF THE IMPROVEMENTS POSSIBLE, AND A COUPLED EFFICIENCY FOR USE WITH COLLECTORS.
A COMPARISON WITH A CONVENTIONAL ABSORPTION CHILLER IS MADE.

SOLAR COLLECTORS

THE PERFORMANCE OF SOLAR COLLECTORS IS ANALYSED AT VARYING COLLECTION TEMPERATURES, USING SIMPLIFIED FORMULAE FOR FLAT PLATE AND EVACUATED TUBE TYPES.

THE EXCESS CAPACITY AT CONDITIONS OF DEHUMIDIFIER PART LOAD IS USED TO JUSTIFY ENERGY STORAGE EITHER BY OVER-REGENERATION OF THE ABSORBENT OR BY COLLECTION OF HOT WATER. CRITERIA FOR DECIDING STORAGE AND COLLECTOR SIZES ARE SUGGESTED, AND THE BASIS AND METHOD OF ANALYSIS OF METEOROLOGICAL DATA ARE GIVEN.

ALTERNATIVE USES OF EXCESS SOLAR COLLECTION CAPACITY FOR DOMESTIC HOT WATER SERVICE AND MID SEASON HEATING ARE ANALYSED.
THE PROBABLE ADDITIONAL USES OF THE DEHUMIDIFIERS FOR HEAT RECLAIM IN ALL FRESH AIR SYSTEMS ARE SHOWN.

ENERGY SAVINGS & COSTS

THE ENERGY SAVINGS ARE EVALUATED ON THE BASIS OF THE COMPARATIVE ENERGY CONSUMPTION OF A CONVENTIONAL SYSTEM AND A SYSTEM CONTAINING A DEHUMIDIFIER.
THE BULK OF THE SAVING IS OBTAINED BY OMITTING THE MECHANICAL

CHILLER, BUT THE SAVING IS REDUCED BY 25 - 30 % THROUGH THE INCREASED ENERGY CONSUMPTION OF SUPPLY AND OTHER FANS.
AN ENERGY BALANCE IS DRAWN UP FOR THE EXAMPLE SYSTEM.

CRITERIA FOR COST COMPARISONS ARE GIVEN, AND THE IMPORTANCE OF TOTAL BUILDING COSTS STRESSED. PROBABLE TRENDS IN COSTS ARE SUGGESTED AND THE SAVINGS FOR THE EXAMPLE SYSTEM ARE EVALUATED. PAYBACK PERIODS ARE ESTIMATED FOR A SYSTEM FINANCED BY A LOAN, NET INTEREST 11.5 % PER ANNUM WITH FUEL INFLATION AT 14 % PER ANNUM.

THE LIFE CYCLE OF THE EQUIPMENT IS EXPECTED TO BE THE SAME AS THAT FOR CONVENTIONAL PLANT. THE MAINTENANCE REQUIRED IS ALSO EXPECTED TO BE COMPARABLE IN COST AND SKILLS.

THE DESIGN AND SELECTION OF A SYSTEM SUITABLE FOR TESTING THE PERFORMANCE OF SOLAR POWERED SYSTEMS ARE DISCUSSED, WITH AN INDICATION OF THE POSSIBILITIES OF FURTHER STUDIES OF SEVERAL OF THE COMPONENTS OPERATING UNDER DIFFERENT BUT SIMILAR CIRCUMSTANCES.

CONCLUSIONS

THE FOLLOWING CONCLUSIONS CAN BE DRAWN FROM THE ANALYSIS :

1. CHEMICAL DEHUMIDIFIERS WITH SOLAR HEATED REGENERATORS CAN BE USED TO PROVIDE LATENT COOLING IN MOST CLIMATES.
   BOTH LIQUID AND SOLID ABSORBENT DEHUMIDIFIERS ARE SUITABLE.

2. SIGNIFICANT ENERGY SAVINGS RESULT FROM THEIR USE.

3. ECONOMIC BENEFITS WILL DEPEND ON THE TAXATION SYSTEM AND CAPITAL CHARGE ARRANGEMENTS WHICH APPLY TO THE PURCHASER OF THE SYSTEM, AND ON WHETHER THE INVESTMENT REQUIRED IS TAKEN FROM PROFITS OR CAPITAL.
   BASED ON VERY PESSIMISTIC ASSESSMENT, A SYSTEM BUILT WITH

CAPITAL BORROWED ON A LONG TERM LOAN WITH TAX RELIEF ON THE INTEREST ONLY, SHOWS A RETURN AT A PERIOD SLIGHTLY LONGER THAN THE EXPECTED PLANT REPLACEMENT CYCLE.

4. THE PERFORMANCE OF THE COMBINED SOLAR COLLECTOR, DEHUMIDIFIER AND AIR CONDITIONING SYSTEMS SHOULD BE CONFIRMED BY THE CONSTRUCTION OF NEW SYSTEMS OR MODIFICATIONS OF EXISTING SYSTEMS.
   IF POSSIBLE TWO DIFFERENT CLIMATES SHOULD BE CHOSEN.

TITLE : CONSTRUCTION OF A COMPLETE ALL SEASON CONDITIONING WITH SOLAR ENERGY OF AN OFFICE BUILDING OF 260 m2 AND ITS OPERATION

CONTRACT NR : 121-76-ESI

ORGANIZATION : NUOVO PIGNONE S.P.A.
VIA F. MATTEUCCI
I - FIRENZE 2

PROJECT HEAD : . . .

PUBLISHED AS MICROFICHE REPORT EUR 6702 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE AIM OF THE PROJECT IS TO DESIGN, BUILD AND TEST THE EXPERIMENTAL PROTOTYPE OF A SOLAR PLANT, WITH THE FOLLOWING OBJECTIVES :

* CHECK OF THE POSSIBLE ECONOMY
* COLLECTION OF WEATHER DATA
* TEST OF THE PERFORMANCES OF EACH COMPONENT AND OF THE WHOLE SYSTEM
* CHECK OF OPERATING AND MAINTENANCE EXPENSES
* COLLECTED DATA PROCESSING
* ECONOMIC OPTIMISATION OF THE PLANT

DEFINITION

THE SOLAR PLANT WAS DESIGNED AND BUILT TO FIT THE ENERGY REQUIREMENTS FOR HEATING SERVICE WATER ASWELL AS TO PROVIDE THE WINTER HEATING AND SUMMER AIR CONDITIONING OF THE ENTIRE BUILDING. THE PREFABRICATED METAL BUILDING HAS A USABLE SURFACE AREA OF 370 m2, OF WHICH A 260 m2 AREA IS RESERVED FOR OFFICE SPACE.

THE BUILDING WAS DESIGNED ACCORDING TO THE CRITERIA OF "INTEGRATED ARCHITECTURE", NECESSARY TO LOWER UNITARY PRODUCTION COSTS OF THE SOLAR PLANTS AND AT THE SAME TIME TO INSERT THEM HARMONIOUSLY INTO THE ENVIRONMENT.

A WATERPROOFED BASEMENT ROOM WITH A CAPACITY OF +/- 300 m3 IS USED TO INSTALL THE PLANT'S WEEKLY STORAGE TANKS, PUMPS, ABSORPTION REFRIGERATION UNITS, AND THE FLOW RATE MEASURING DEVICES.
SPECIAL CARE HAS BEEN TAKEN IN THE STRUCTURAL DESIGN OF THE BUILDING IN ORDER TO MINIMIZE HEAT DISSIPATION.

THE SOLAR PLANT WAS DESIGNED TO SUPPLY UP TO 100 % OF THE ENERGY REQUIRED FOR SUMMER AIR CONDITIONING AND UP TO 70 % OF THAT REQUIRED FOR HEATING THE OFFICES AND SERVICE WATER IN

WINTER. IN ORDER TO ACHIEVE AN ECONOMY GOAL, IT SEEMES REASONABLE TO REDUCE THE PERCENTAGE OF SOLAR ENERGY USED TO 30-40 %, AND SUPPLY THE RESIDUAL LOAD WITH A CONVENTIONAL SOURCE OF ENERGY.

SOLAR COLLECTORS

THE COLLECTORS HAVE AN EFFECTIVE SURFACE AREA OF 110 m2 ; 50 % FACE SOUTH AND 50 % FACE SOUTH-SOUTHWEST. THEIR TILT ANGLE IS 48 DEG FROM HORIZONTAL.

THE ALUMINIUM ROLL-BOND TYPE COLLECTORS ARE MANUFACTURED ON AN ORIGINAL NUOVO PIGNONE DESIGN CREATED AFTER A LONG SERIES OF FLUID DISTRIBUTION TESTS ON DIFFERENT ROLL-BOND COLLECTORS. THEY ARE COATED WITH BLACK PAINT ; THE REAR INSULATION CONSISTS IN POLYURETHANE FOAM.

IN KEEPING WITH THE CONCEPT OF INTEGRATED ARCHITECTURE, THE GLASS PANES OF THE PANEL WITH THEIR ALUMINIUM FRAME SUPPORTS BELONG TO THE EXTERNAL WALL OF THE BUILDING.

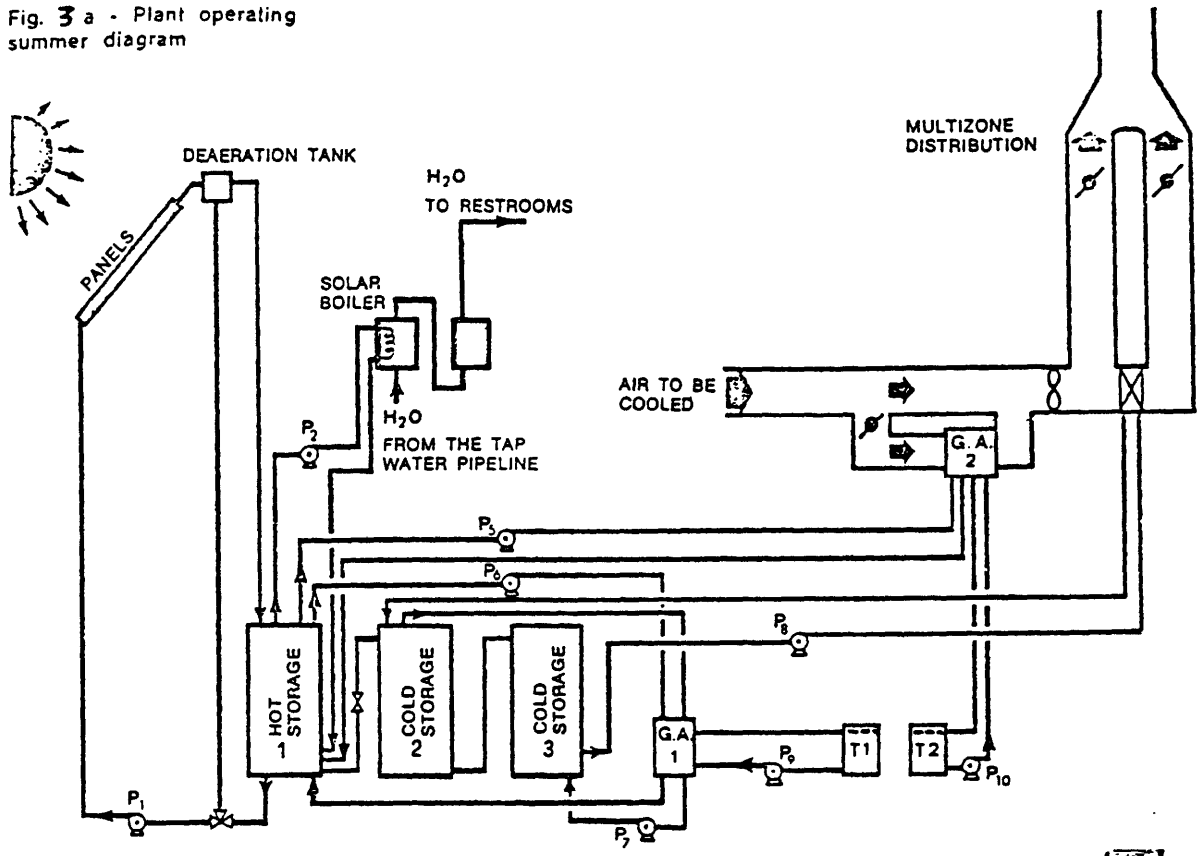
SOLAR PLANT

THE PLANT OPERATING DIAGRAM IS GIVEN AT THE NEXT PAGE.

EACH STORAGE TANK HAS A CAPACITY OF 5.5 m3.

A COMPLETELY AUTOMATIZED DATA ACQUISITION SYSTEM CAN COLLECT UP TO 100 DIFFERENT VALUES OF WORKING PARAMETERS, AT PREDETERMINED TIME INTERVALS. THESE DATA MAY BE IMMEDIATELY PRINTED FOR CHECKING, OR PUNCHED, FOR COMPUTER PROCESSING.

Fig. 3 a - Plant operating summer diagram



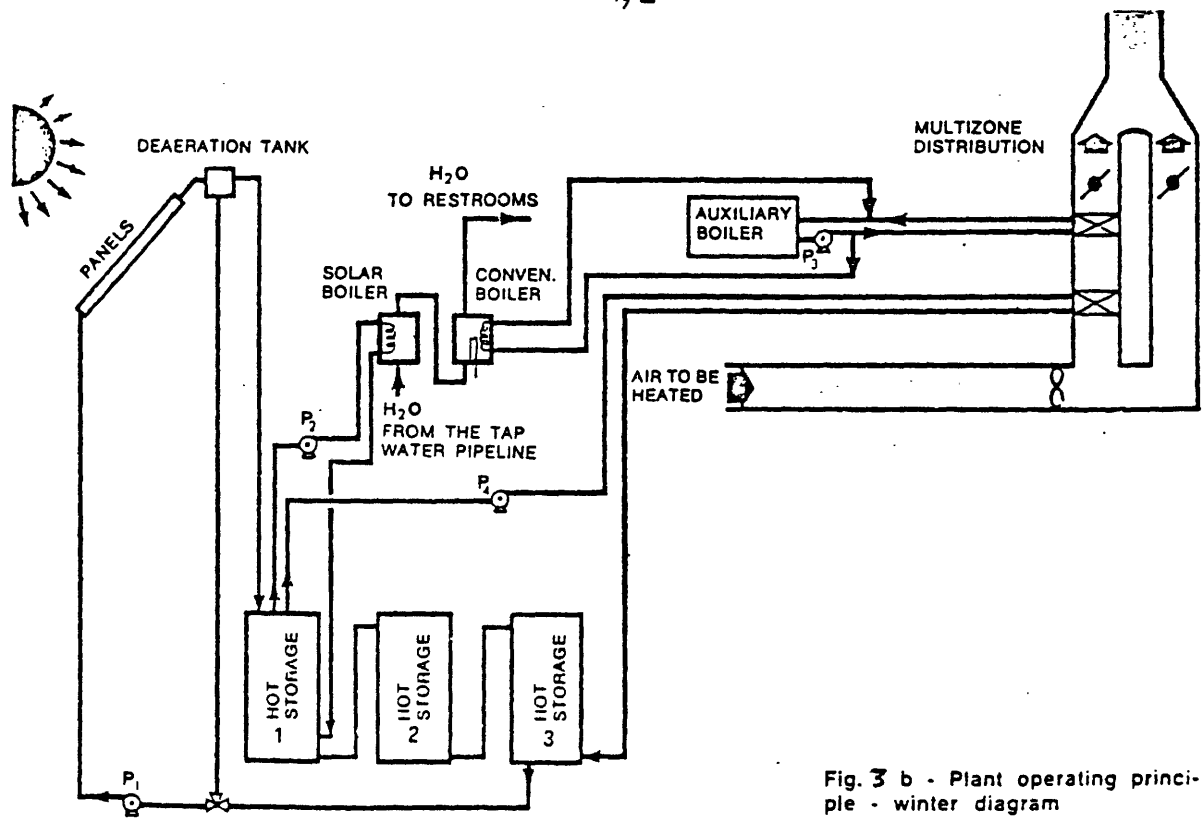


Fig. 3 b - Plant operating principle - winter diagram

WINTER HEATING TESTS

THE SPACE HEATING HAS BEEN WORKING SATISFACTORILY FROM THE 20TH OF NOVEMBER 1977 TILL THE 21TH OF APRIL 1978.
THE MAIN THINGS TO BE NOTICED WERE THAT THE BUILDING INSULATION WAS FOUND TO BE BETTER THAN PREDICTED, AND THAT THE INDUSTRIAL AREA INFLUENCED THE COLLECTOR EFFICIENCY : THE DIRT LAYER THAT FELL OVER THE GLASS COVERS REDUCED THE EFFICIENCY BY 10 %.

ON THE WHOLE, THE SOLAR CONTRIBUTION WAS 5.435.500 KCAL, THAT IS 66.7 % OF THE BUILDING REQUIREMENT.

SUMMER COOLING TESTS

THE FIRST TESTS STARTED AT THE END OF APRIL 1978.
THE FIRST COOLING UNIT (WATER CHILLER) WORKED FOR ONE WEEK AND THEN BROKE DOWN SUDDENLY, PROBABLY DUE TO A CRYSTALLISATION OF THE LITHIUM BROMIDE IN THE STRONG SOLUTION.
ALL EFFORTS TO REPARE THE UNIT WERE USELESS.

THE SECOND UNIT STARTED WORKING ONLY WHEN THE HOT WATER INLET TEMPERATURE WAS HIGHER THAN 93 C, AND ITS COOLING CAPACITY WAS ABOUT 1/3 OF THAT CERTIFIED BY THE MANUFACTURER, WHILE THE COP WAS ABOUT 0.30. IN CONTINUOUS RUNNING, THIS UNIT HAD A PRACTICALLY NEGLIGIBLE COOLING CAPACITY UNDER 86 C OF WATER INLET TEMPERATURE.

THE FIRST UNIT WAS REPAIRED AT THE END OF MAY AND GAVE SATISFACTION IN SUPPLYING THE BASE LOAD. THE SECOND ONE WAS ABLE TO SUPPLY THE PEAK LOAD, BUT ONLY WHEN VERY HIGH INSOLATION OCCURED.
AS A RESULT, AN ELECTRICAL REFRIGERATION UNIT HAD TO BE INSTALLED, AND THE SOLAR COLLECTORS HAD BEEN WORKING AT A HIGHER MEAN TEMPERATURE - SO, WITH A WORSE EFFICIENCY - THAN WAS EXPECTED.

ON THE WHOLE, THE SOLAR CONTRIBUTION IN SUMMER CONDITIONING WAS 6.410.900 KFRIG, THAT IS 76.9 % OF THE BUILDING DEMAND.

CONCLUSIONS

AS FAR AS SUMMER COOLING IS CONCERNED, THE ENERGY SAVING HAS BEEN 2174 KWH, BY COMPARISON WITH A CONVENTIONAL ELECTRICAL REFRIGERATION UNIT.

FOR THE HEATING OF SERVICE WATER, THE FIRST YEAR RESULTS LED TO A SOLAR CONTRIBUTION OF 1.244.200 KCAL, THAT IS 86.2 % OF THE REQUIREMENT; THIS MEANS AN ELECTRIC ENERGY SAVING OF 1523 KWH.

ON THE WHOLE, THE ELECTRIC ENERGY SAVING WAS 3697 KWH, EQUIVALENT TO 1060 KG OF FUEL, IN ADDITION WITH 906 KG OF FUEL SAVED FOR WINTER SPACE HEATING. THE TOTAL FUEL SAVING IS THUS EQUAL TO 1966 KG.

THE SEASONAL COLLECTOR EFFICIENCY HAS BEEN, FOR THE FIRST YEAR, 31 % DURING WINTER AND 22 % DURING SUMMER.

THE MAIN RESTRICTION ON THE WHOLESALE ADOPTION OF SOLAR PLANTS IS ECONOMICS. THE TECHNOLOGY FOR USING SOLAR ENERGY IS SIMPLE; THE MOST SIGNIFICANT PROBLEMS ARE IN THE AREA OF REFINEMENTS IN MASS PRODUCTION AND CONSTRUCTION TECHNIQUES.

TITLE : DEVELOPMENT OF EVAPORATIVE COOLING PACKING

CONTRACT NR : 644-78-8-ESUK

ORGANIZATION : WATERMEYER, LEGGE, PIESOLD & UHLMANN
35-41 STATION ROAD
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PROJECT HEAD : J. TATTERSFIELD

PUBLISHED AS MICROFICHE REPORT EUR 7709 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE RESEARCH

THE AIM OF THIS RESEARCH PROGRAMME WAS TO INVESTIGATE AND EVALUATE EVAPORATIVE COOLING TOWER PACKINGS, TEST EXISTING AND NEW PACKS, AND PUBLISH HEAT TRANSFER CHARACTERISTICS AND AIRFLOW RESISTANCE FIGURES IN A COMPARABLE FORM. THE FIELD OF STUDY WAS TO BE ORIENTED TOWARDS PACKS SUITABLE FOR SMALL TOWERS, PERHAPS SERVING SOLAR COOLING SYTEMS IN MAJOR DWELLING COMPLEXES SUCH AS BLOCKS OF FLATS, OFFICES, PUBLIC BUILDINGS, HYPERMARKETS AND THE LIKE.

EVAPORATIVE COOLING PACKING

AFTER A STATE-OF-THE-ART REVIEW, IT IS CONCLUDED THAT MECHANICAL DRAUGHT TOWERS, PARTICULARLY INDUCED DRAUGHT, WILL BE MOST SUITABLE FOR THE APPLICATIONS ENVISAGED IN SOLAR COOLING SYTEMS.
THIS REPORT DEALS CHIEFLY WITH THIS TYPE OF TOWER, PARTICULARLY OF THE COUNTERFLOW VARIETY, AND ALL COMMENTS REGARDING PACK PERFORMANCES ARE MADE WITH RESPECT TO THIS FACT.

A DISCUSSION OF THE RELATIVE MERITS AND DEMERITS IS MADE FOR VARIOUS TYPES OF PACK : SPLASH PACKS, FILM PACKS AND EXTENDED FILM PACKS.

THEORETICAL CONSIDERATIONS

THE HEAT TRANSFER EQUATION IS STATED FROM MERKEL'S THEORY (1925). IT IS SHOWN THAT THE HEAT TRANSFER CHARACTERISTICS MAY BE CONVENIENTLY EXPRESSED IN THE FOLLOWING SIMPLIFIED FORM :

$$(K.a.V)/L = \lambda (L/G)^{-N}$$

WHERE :

K = COEFFICIENT OF MASS TRANSFER PER UNIT DIFFERENCE IN ABSOLUTE HUMIDITY

a = AREA OF TRANSFER SURFACE PER UNIT OF TOWER PACKED VOLUME

L = MASS WATER FLOW

G = MASS AIR FLOW PER UNIT AREA OF PACKING

λ, N = CONSTANTS

THE COMPUTATION OF COOLING REQUIREMENTS MAKES USE OF A FOUR-POINTS NUMERICAL INTEGRATION FOLLOWING TCHEBYCHEFF'S METHOD.

AIR RESISTANCE COMPUTATION

PRESSURE DROP ACROSS THE PACK IS EXPRESSED AS A MULTIPLE OF THE UNIT VELOCITY HEAD RELEVANT TO THE EQUIVALENT EMPTY TOWER AIR FLOW VELOCITY.
SO THE AIR RESISTANCES MEASURED AS WATER GAUGE HEAD HAVE TO BE CONVERTED IN TERMS OF THIS MULTIPLE.

IT HAS BEEN FOUND THAT PACK RESISTANCES CAN BE CONVENIENTLY EXPRESSED AS A FUNCTION OF THE WATER AND AIR FLOW RATES BY AN EQUATION OF THE FORM :

$$NP = A \cdot L^{B} \cdot G^{C}$$

WHERE A, B, C ARE CONSTANTS. THIS EQUATION CAN BE USED WITHOUT INTRODUCING TOO MAJOR INACCURATIES, OVER THE RANGE OF WATER AND AIR LOADINGS TO BE ENCOUNTERED IN PRACTICAL SITUATIONS.

COOLING TOWER SELECTION AND DESIGN

A DISCUSSION OF THE MAIN DESIGN PARAMETERS (I.E. AMBIENT AIR CONDITIONS, WATER TEMPERATURES AND WATER RATE, AIR RATE) IS GIVEN. THE EFFECTS OF ALTITUDE AND CONTAMINED WATERS ARE ALSO COMMENTED.

FINALLY, A DETAILED "DECISION TABLE" IS ESTABLISHED AND DISCUSSED IN A USEFUL FORM, TAKING THE FOLLOWING CRITERIA INTO ACCOUNT : TYPE OF TOWER / MECHANICAL TOWER CONFIGURATION / AIR FAN DRIVE / DIRECTION OF AIR FLOW / WATER DISTRIBUTION SYSTEM / PACKING TYPE / PACKING MATERIAL / SPRAY ELIMINATOR MATERIAL.

FOR WHAT CONCERNS THE PACKING DESIGN, THE MOST SENSITIVE AND DIFFICULT DESIGN REQUIREMENTS ARE HEAT TRANSFER AND PRESSURE DROP, WHICH ARE OF COURSE CONFLICTING. AN ECONOMIC COMPROMISE HAS THEREFORE TO BE REACHED.

THE DIFFICULTY OF OBTAINING A LARGE NUMBER OF ACCURATE COSTS PREVENTS A POSSIBLE METHOD OF ASSESSING PACKS, WHICH SHOULD BE BASED ON UNITS OF TRANSFER PER UNIT COST.

EXPERIMENTAL INVESTIGATIONS

FOR THE PURPOSE OF OBTAINING PACK CHARACTERISTICS, OBSERVATIONS WERE RECORDED OF THE FOLLOWING PARAMETERS : AIR AND WATER FLOW RATES / WET AND DRY BULB AIR INLET TEMPERATURES / WET BULB EXIT AIR TEMPERATURE / HOT AND COOLED WATER TEMPERATURES / AIR RESISTANCE.

TO ASSESS THE PERFORMANCES OF THE PACK ALONE, APPROPRIATE DEDUCTIONS OF THE OBSERVED CHARACTERISTICS OF THE EMPTY TOWER HAVE BEEN MADE.

BOTH PACK TRANSFER AND RESISTANCE CHARACTERISTICS ARE PRESENTED FOR UNIT DEPTH OF PACK, ON "DATA SHEETS". THE RESULTS OF THE PRESENT WORK ARE BROUGHT TOGETHER WITH RESULTS OBTAINED FROM A PREVIOUS RESEARCH PROGRAMME. MORE THAN SEVENTY DATA SHEETS ARE PRESENTED.

IT SHOULD BE STRESSED THAT THE RANGES OF WATER AND AIR MASS

FLOW RATES TESTED ARE STATED FOR REFERENCE. EXTRAPOLATION OF CHARACTERISTICS BEYOND THESE LIMITS SHOULD BE TREATED WITH EXTREME CAUTION.
PACKS ARE CLASSIFIED INTO SPLASH, FILM AND EXTENDED FILM CATEGORIES AND THE ASSEMBLED CONFIGURATION IS DESCRIBED BY A DIMENSIONED SKETCH.

CONCLUSION

TESTING OF EVAPORATIVE COOLING PACK UNDER CONTROLLED CONDITIONS IS THE ONLY TECHNIQUE CURRENTLY AVAILABLE FOR ESTABLISHING HEAT TRANSFER AND AIR RESISTANCE CHARACTERISTICS.

THE TEST WORK UNDERTAKEN DEMONSTRATED THE DIFFICULTY OF OBTAINING CONSISTENT RESULTS COMPARABLE WITH PREVIOUS RESEARCH. HOWEVER, THE TEST RESULTS OBTAINED ARE DEEMED SUFFICIENTLY ACCURATE FOR USE IN THE PREPARATION OF PRELIMINARY DESIGNS FOR COUNTERFLOW COOLING CELLS.

FOR CONSTRUCTION OF A SMALL CELL TO SERVE A SOLAR COOLING SYSTEM SUITABLE FOR USE IN LARGE DWELLINGS, EXTENDED FILM PACK IS LIKELY TO BE THE MOST COMPETITIVE.

WHILST POTENTIAL ENERGY SAVINGS IN THE RUNNING COST OF THE PUMP AND FAN OF A COOLING TOWER ARE SMALL, CAREFUL SELECTION OF THE TYPE OF PACK EMPLOYED TO SERVE A PARTICULAR COOLING DUTY MAY HAVE A MARKED EFFECT ON THE CAPITAL EXPENDITURE REQUIRED FOR CELL CONSTRUCTION AND INSTALLATION.

FINALLY, NO CONVENIENT METHOD WAS FOUND TO ENABLE DIFFERENT PACKS TO BE READILY COMPARED. CURRENTLY, THE ONLY METHOD OF EVALUATING PACKS IS BY COMPARISON OF DIFFERENT TOWER DESIGNS AND ON COST CONSIDERATIONS.

TITLE : A CRITICAL APPRAISAL OF MONITORING PROCEDURES IN SOLAR HEATED HOUSES

CONTRACT NR : 509-78-ESUK

ORGANIZATION : STEPHEN GEORGE & PARTNERS
5 DRYDEN STREET
GB - LONDON WC2E 9NW

PROJECT HEAD : C. WHITTAKER

PUBLISHED AS MICROFICHE REPORT EUR 7710 EN, AVAILABLE FROM OFFICE FOR OFFICIAL PUBLICATIONS, LUXEMBOURG, B.P. 1003.

AIM OF THE PROJECT

THE MAIN OBJECTIVE OF THIS STUDY HAS BEEN TO INVESTIGATE THE MONITORING ARRANGEMENTS IN EXISTING SOLAR HEATED HOUSES, AND TO RECOMMEND A COURSE OF ACTION FOR ANY FUTURE FIELD TRIALS SPONSORED BY THE EUROPEAN COMMISSION.

THE REPORT IS PRESENTED IN TWO VOLUMES. VOLUME II CONTAINS CASE STUDIES ON A TOTAL OF TWENTY FOUR MONITORED SOLAR HEATING PROJECTS, LOCATED IN THE EEC AND SWEDEN.
VOLUME I CONTAINS AN ANALYSIS OF THE INFORMATION COLLECTED DURING THE SURVEY PERIOD, AND THE STUDY'S MAIN RECOMMENDATIONS.

SOLAR HOUSES

THE CRITERIA FOR SELECTION OF SUITABLE PROJECTS WERE :

* THEY SHOULD BE DOMESTIC APPLICATIONS OF SOLAR ENERGY, DESIGNED TO PROVIDE PARTIAL SPACE/WATER HEATING
* BOTH ACTIVE AND PASSIVE SYSTEMS SHOULD BE INCLUDED IN THE SURVEY
* PROJECTS SHOULD BE COMPLETED AND MONITORED FOR SOME PERIOD OF TIME, PREFERABLY AT LEAST SIX MONTHS.

THE SURVEY HAS IDENTIFIED A TOTAL OF 24 MONITORED SOLAR ENERGY PROJECTS WHICH SATISFY THESE CRITERIA.
THEY ARE LISTED IN THE TABLE NEXT PAGE. INFORMATIONS ON THEIR CHARACTERISTICS ARE ALSO GIVEN IN THIS TABLE.

THE TABLE ILLUSTRATES THE ENORMOUS DIVERSITY IN THE TYPES OF SOLAR HEATING SYSTEM FOUND AT THE VARIOUS SITES, AND SHOWS THE DIFFICULTY IN ESTABLISHING A BASIS FOR COMPARING THE PERFORMANCE OF DIFFERENT SYSTEMS INSTALLED IN INDIVIDUAL 'ONE OFF' SITUATIONS.

TABLE 2 SYSTEM PARAMETERS

		SURVEY PROJECTS	LAT. °N	COLL. AREA m²	TILT IN °	COLLECTOR TYPE	HEAT TRANS	STORAGE m³	SPACE HEAT. DIST.	AUX. HEAT	SPECIAL FEATURES	CALC. HEAT LOAD kWh
U.K.	1	MILTON KEYNES	52-03	35	30	Aluminium Roll Bond	Water	4 water	Warm air	gas		8,000
	2	MACCLESFIELD	53-15	42	30	Aluminium	Water	3+2 ..	Radia-tors	oil	HP.CV.HR.	
	3	BLYTH	53	40	22½	Copper	Water	4 ..	Warm air	elec.		
	4	ANGLESEY	51-15	33	30	Aluminium Roll Bond	Water	2,55,.	Under floor	elec. wood		17,000
W.GERMANY FRANCE	5	ODEILLO	42-31	55	90	Concrete	Air	48 Conc.	Warm air	elec.	Passive	
	6	LE HAVRE/ARAMON	49-30/44	40/38	4060 vert	Aluminium Roll Bond	Water	3/4 water	Warm A Floor	elec.		
	7	BLAGNAC	43-38	30	75	Steel	Water	3 ..	Warm air	gas		
	8	DOURDAN	48-50	70	75	Steel	Air	40 rock	Warm air	elec.	Air system H.P.	26,000
	9	AACHEN	50-76	20	48	Evac. Panels	Water	4+43	Radia-tors	elec.	HP.CV.HR.	4,000
	10	ESSEN	51-27	65	48	Heat Pipe	Water	3.6+2.4	Floor	elec.	HP.	
	11	MUNICH	48	35/80	-/30	Aluminium Roll Bond	Water	4 water	Rads. Floor	oil	Earth Store	
	12	HEIDELBERG	49-25	71.5	48	Aluminium Roll Bond	Water	8+2	Floor	oil	Heat of Fusion Storage HP.	20,000
HOLLAND	13	OSS	53	20	60	Concrete	Air	6 Conc.	Warm Air	gas	Air System	
	14	EINDHOVEN	51-26	51	48	Aluminium Roll Bond	Water	4 water	Warm Air	gas	Stratification	19500
	15	ZOETEMEER	52	35	60	Steel	Water3 Air 1	2 ..	Rad.U/ Fl.W/A	gas	Dist. Systems	
	16	APELDOORN	52	17.6	58	Steel	Water	10.9 Conc.	Floor	gas	Cooling Circuit	
SCANDINAVIA	17	LYNGBY	55-43	42	90	Steel	Water	30	Warm Air	elec.	CV. HR.	
	18	GREVE	56	50	38	Steel	Water	5	Radia-tors	oil	CV. HR.	18,3000
	19	MALMOE	45	52	70	Steel	Water	3.4	Floor	elec.	CV. HR.	
	20	LINKOPING	58-22	50	45	Steel	Water	8+3.2	Warm air	elec.		
	21	TABY	59-05	24	35	Copper	Water	10	Warm air	elec.	HP. CV. HR.	
ITALY	22	LOCARNO										
	23	PORDENONE										
	24	BOLOGNA										

H.P. Heat Pump C.V. Controlled Ventilation H.R. Heat Recovery

FACTORS AFFECTING SYSTEM PERFORMANCE

AN EXAMINATION OF THE CHARACTERISTICS OF EACH PROJECT HAS REVEALED A GREAT MANY VARIABLES WHICH HAVE A DIRECT INFLUENCE ON SYSTEM PERFORMANCE. THESE CAN BE SUMMARIZED BRIEFLY AS :

* LOCAL CLIMATE
* BUILDING THERMAL CHARACTERISTICS
* SYSTEM PARAMETERS
* USER DEMAND
* FREE HEAT GAINS.

THESE KEY FACTORS HAVE BEEN ANALYSED IN TERMS OF THEIR RELATIONSHIP TO ANY PROPOSED PROGRAMME OF MONITORING.
THIS ANALYSIS PROVIDES A FRAMEWORK FOR DETERMINING MONITORING STRATEGIES AND PROCEDURES.

REPORTING OF RESULTS

FULL RESULTS ARE AVAILABLE ONLY FOR NINE OF THESE PROJECTS :
1 - 5 - 6 - 9 -12 - 13 - 17 - 19 - 20.
REPORTS HAVE BEEN OBTAINED AND STUDIED IN ORDER TO DETERMINE WHAT EACH PROJECT HAS ACHIEVED, HOW THE RESULTS HAVE BEEN PRESENTED, AND TO WHAT EXTENT COMPARISONS CAN BE MADE.

AT THE CURRENT STAGE IT IS CLEAR THAT MOST GROUPS ARE CONCERNED ALMOST EXCLUSIVELY WITH LEARNING HOW THE SYSTEMS ARE OPERATING, AND ACQUIRING EXPERIMENTAL DATA IN ORDER TO OPTIMIZE THE VARIOUS SYSTEM COMPONENTS, AND THUS ACHIEVE BETTER OVERALL PERFORMANCE. THERE IS CONSIDERABLE VARIETY IN THE WAY THAT RESULTS ARE PRESENTED, BUT TWO DISTINCT TYPES OF RESULTS CAN BE IDENTIFIED : 1- THOSE DESCRIBING THE SOLAR ENERGY SYSTEM, AND 2- THOSE DESCRIBING THE OVERALL THERMAL BEHAVIOUR OF THE HOUSE.

IN NEARLY ALL CASES, THE PUBLISHED FIGURES FALL WITHIN CATEGORY 1-, ALTHOUGH HEAT BALANCE CALCULATIONS ARE SOMETIMES GIVEN.

ECONOMIC EVALUATION

THERE IS NO ACCURATE INFORMATION ON THE 'EXTRA COVER' CAPITAL COSTS INVOLVED BY THE PROJECTS.
WHILST THERE WAS CONSIDERABLE OPTIMISM AMONG THE DIFFERENT GROUPS, CONCERNING THE COMMERCIAL POTENTIAL FOR SOLAR WATER HEATING SYSTEMS, THERE WAS GENERAL AGREEMENT THAT SPACE-HEATING SYSTEMS WOULD REMAIN UNECONOMIC FOR THE FORSEEABLE FUTURE.

DATA ACQUISITION AND ANALYSIS

THE INSTRUMENTS USED AND THEIR ACCURACY ARE PRESENTED IN THE REPORT. MORE PARTICULARLY, THE MEASUREMENT TECHNIQUES OF : SOLAR RADIATION, TEMPERATURE, MASS FLOW, HEAT FLOW, AND AUXILIARY HEATING ARE DISCUSSED, AND RECOMMENDATIONS ARE SUGGESTED WHICH SHOULD LEAD TO AN ACCEPTABLE DEGREE OF ACCURACY.

IN NEARLY ALL CASES, THERE IS SOME FORM OF AUTOMATIC RECORDING OF DATA. IN EIGHT OF THE PROJECTS STUDIED, CONVENTIONAL MULTI-CHANNEL CHART RECORDERS HAVE BEEN USED. IN PRACTICE, THESE HAVE PROVED TO BE FAIRLY RELIABLE AND HAVE THE GREAT ADVANTAGE THAT THE STATE OF THE SYSTEM CAN BE ASSESSED AT ANY POINT IN TIME. THE MAJOR DISADVANTAGE IS THAT ANALYSIS OF THE DATA IS AN EXTREMELY LABOURIOUS AND TIME CONSUMING PROCESS.

ON 14 OF THE PROJECTS, MORE SOPHISTICATED DATA LOGGING SYSTEMS HAVE BEEN EMPLOYED, WITH VARIOUS DEGREES OF SUCCESS.
EXPERIENCE HAS SHOWN THAT IT CAN TAKE 3-6 MONTHS TO GET THE LOGGING EQUIPMENT WORKING IN A RELIABLE MANNER.

ONE AREA WHICH NEED PARTICULAR ATTENTION IN THIS FIELD IS THE COST OF PRODUCING THE NECESSARY SOFTWARE FOR THE FIELD TRIALS. WHILE SOME OF THE WORK MAY ALREADY HAVE BEEN DONE IT WOULD BE PRUDENT TO ASSUME THAT IT WILL HAVE TO BE VIRTUALLY RESTARTED AFTER THE DECISIONS ARE MADE REGARDING THE ANALYSIS REQUIRE-

MENTS FOR THE PROJECT.

24 CASE STUDIES

IN THIS PART, A BRIEF DESCRIPTION OF EACH SOLAR HEATED HOUSE IS GIVEN TOGETHER WITH DETAILS OF THE SYSTEM INSTALLED AND NOTES ON ANY SPECIAL DESIGN FEATURES.
A SCHEMATIC DIAGRAM OF EACH INSTALLATION IS ALSO INCLUDED AND THE KEY MEASURING POINTS LISTED, WITH NOTES ON THE METHOD OF DATA ACQUISITION AND ANALYSIS.

FINALLY, AN APPRAISAL IS MADE OF THE EXPERIENCE GAINED DURING THE MONITORING PERIOD AND THE RESULTS OBTAINED.

CONCLUSION

THE MAIN CONCLUSION DRAWN IS THAT THE RESULTS OBTAINED SO FAR FROM INDIVIDUAL EXPERIMENTAL HOUSES ARE NOT EASILY RELATED TO THE FIELD OF CONVENTIONAL FAMILY HOUSING OR TO THE COMMERCIAL DEVELOPMENT OF DOMESTIC SOLAR ENERGY SYSTEMS.
THEY ARE NONETHELESS USEFUL FOR MAKING AN APPRAISAL OF PARTICULAR TYPES OF SYSTEM, IN RELATION TO A UNIQUE SET OF PARAMETERS.

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