



TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and
Mechatronics

CONTROL SYSTEM FOR THE SHOWERLOOP
RINGDUŠŠI JUHTSÜSTEEM

MASTER THESIS

Student Divya Dihuliya

Student code 144968

Supervisor Prof. Mart Tamre

Tallinn, 2017

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material.

All works, major viewpoints and data of the other authors used in this thesis have been referenced.

"....." 201.....

Author:

/signature /

Thesis is in accordance with terms and requirements

"....." 201....

Supervisor:

/signature/

Accepted for defence

"....."201....

Chairman of theses defence commission:

.....

/name and signature/

MSc THESIS TASK SHEET

2016 autumn semester

Student Divya Dihuliya
 Study program Master of Science in Mechatronics
 Specialty Mechatronics
 Supervisor Prof. Mart Tamre

THESIS TOPIC:**English:** Control system for the Showerloop.**Estonian:** Ringdušši juhtsüsteem

No.	Task description	Proposed time for completion
1	Literature Review: To search literature related to system and control solutions	30 /10/2016
2	Problem Formulation: Imposed Requirements Data Storage and Communication consideration MCU/ MPU/modules consideration and selection Control components consideration and selection	30/11/2016
3	Proposing solution: Hardware Consideration Selecting hardware for control board according to requirements.	06/11/2016
4	Hardware consideration: Selecting hardware for control /board according to requirements.	06/11/2016
5	Software Consideration: Deciding on software tools which validate to imposed requirements.	06/11/2016

6	Schematic: Drawing the schematic for control using the selected controller and circuitry. Proof of suitability of hardware should be done.	30/11/2016
7	Writing Code: Writing code to control system according to imposed requirements	15/12/2016
8	Testing: Testing the schematic and code.	05/01/2017

Language of the thesis:

English

Deadline for submission of the thesis:

10/01/2017

Student

Divya Dihuliya /signature/

date

Supervisor

Mart Tamre /signature/

date

TABLE OF CONTENTS

AUTHOR'S DECLARATION.....	2
TASK SHEET.....	3
TABLE OF CONTENTS.....	5
LIST OF FIGURES.....	7
EESSÕNA.....	9
PREFACE.....	10
LIST OF ABBREVIATIONS AND SYMBOLS.....	11
1. INTRODUCTION.....	12
1.1 PROBLEM STATEMENT.....	12
1.2 SIGNIFICANCE OF WORK.....	12
1.3 OBJECTIVES AND GOALS.....	12
1.4 SCOPE.....	13
2. SHOWERLOOP AND OTHER CLOSEDLOOP SHOWERS.....	14
2.1 OTHER CLOSEDLOOP SHOWERS.....	14
2.2 SHOWERLOOP.....	17
3. THEORETICAL BACKGROUND.....	23
3.1 CONTAMINANTS IN SHOWER WATER.....	23
3.2 POSSIBLE CLEANING TECHNOLOGIES.....	23
4. APPLICABLE STANDARDS.....	25
4.1 STANDARDS APPLICABLE TO WATER.....	26
4.2 STANDARDS APPLICABLE TO SHOWER.....	28
5. SELECTION OF CONTROLLER.....	29
5.1 SELECTION OF MICROCONTROLLER.....	29
5.2 SELECTION OF PLC.....	34
6. CONTROL SYSTEM DESIGN.....	38
6.1 ELECTRICAL SCHEME OF THE SYSTEM.....	39
6.2 SYSTEM IMPLEMENTATION.....	41
7. SOFTWARE DEVELOPMENT.....	47
7.1 ALGORITHM.....	47
7.2 USER INTERFACE.....	51
8. TEST AND TEST RESULTS.....	55
8.1 TEST CONDITIONS.....	56
8.2 TEST RESULTS.....	56

9. CONCLUSION AND FUTURE WORK.....	59
10. SUMMERY.....	61
11. KOKKUVÕTE.....	62
REFERENCES.....	63
APPENDIX 1. Level Switch datasheet.....	67
APPENDIX 2. Three-way solenoid valve.....	68
APPENDIX 3. Four-way solenoid valve.....	69
APPENDIX 4. Interface relay.....	73
APPENDIX 5. Flow meter datasheet.....	74
APPENDIX 6. Input output module.....	75
APPENDIX 7. Power module.....	77
APPENDIX 8. Logic module.....	80
APPENDIX 9. Electrical scheme.....	82
APPENDIX 10. User Manual for software.....	84

LIST OF FIGURES

Figure1. Quench shower tank and drain.....	15
Figure2. Cintep shower block diagram.....	16
Figure3. Orbital Shower.....	16
Figure 4. Showerloop Scheme.....	17
Figure 5. Filter in Showerloop.....	19
Figure 6. Curiosity PIC32MX470.....	29
Figure7. Curiosity HPC development board.....	30
Figure8. EXP-MSP430FR4133 Launchpad.....	30
Figure 9. MSP430FR6989 development board.....	31
Figure 10. Simplelink CC2650 wireless MCU.....	32
Figure 11. Showerloop controlled via PLC.....	35
Figure 12. Scheme of PLC modules.....	36
Figure 13. Hydrodynamic Scheme of Showerloop.....	38
Figure 14. Scheme of Showerloop with backwash.....	39
Figure 15. Electrical scheme of Showerloop.....	41
Figure16. Three-way valve.....	42
Figure 17. Four-way valve.....	42
Figure 18. PT100 Temperature Sensor.....	43
Figure 19. Temperature transmitter.....	43
Figure 20. Temperature sensor wiring.....	44
Figure 21. Solid state relay.....	44
Figure 22. Electrical scheme of pump, heater and UVIR.....	45
Figure 23. Flow chart Recycling.....	48
Figure 24. Flow chart draining.....	49
Figure 25. Flowchart backwash.....	50

Figure 26. Flowchart freshwater mode.....	51
Figure 27. Recycle mode window.....	52
Figure 28. Selecting temperature.....	53
Figure 29. Setting Screen.....	53
Figure 30. Information window.....	54
Figure 31. Message for user.....	54
Figure 32. Alarm no signal.....	55
Figure 33. UVIR service.....	55
Figure 34. Simulation in LOGO Softcomfort.....	56
Figure 35. 0-10 V signal simulation by variable resistor.....	56
Figure 36. Simulation freshwater mode.....	57
Figure 37. Simulation recycle mode.....	58
Figure 38. Simulation drain.....	58
Figure 39. Simulation backwash.....	59

EESSÕNA

Esiteks soovin avaldada tänu lõputöö juhendajale professor Mart Tamrele, Mehhatroonikasüsteemide õppetoolist. Tänu tema toetusele suutsin toime tulla kõigi raskustega magistrikraadi omandamise jooksul. Olen tänulik tema nõuannete eest selle töö kirjutamisel.

Ühtlasi soovin tänada Tallinna Tehnikaülikooli ja Eesti riiki, kes on avanud oma ukсед ja südamed välistudengitele.

Täna ka oma abikaasat Sandeepi, ilma kelle abi ja ohverdusteta poleks see töö olnud võimalik ja poega Ianit, kes andis oma emale motivatsiooni alustatu lõpule viia.

PREFACE

First of all, I would like to thank my thesis supervisor Prof. Mart Tamre, Chair of Mechatronics. His immense support gave me strength to face whatever came along the way while pursuing the degree. I am grateful for his advice and suggestions made during thesis work.

I take this opportunity to thank Tallinn University of Technology and Estonia who opened their doors and hearts to international students.

Thanks to Sandeep, my husband without his support and sacrifices it was not possible and to Ian who gave mummy enough time and motivation to finish what she started.

LIST OF ABBREVIATIONS AND SYMBOLS

DC	Direct current
GND	Ground
PLC	Programmable Logic Controller
PC	Personal Computer
UVIR	Ultraviolet Irradiation Reactor
GACF	Granular Activated Carbon Filter
SF	Sand Filter
ISO	International standards organisation
NANDO	New Approach Notified and Designated Organizations
EU	The European Union
EEA	European Economic Area
CE	Conformity Assessment
USB	Universal Serial Bus
LED	Light Emitting Diode
LOGO0BA8	LOGO logic module 6ED10521MD000BA8

1. INTRODUCTION

Earth is crowded than ever before. We are putting so much pressure on earth's resources that it is interfering with environment and ecosystem. Water is a very important resource for us humans to survive. We engineers can contribute tremendously in bringing down our carbon footprints. Our planet has paid dearly for development and civilisation of humankind.

Taking a shower is part of morning schedule for most of us. Some of us even take it as leisure time and take longer showers. A recyclable shower can prove a boon to water-starved areas and is intelligent to use in general. Most houses around the world include a showering unit. Water that has been treated to potable standards goes down the drain when we take a shower.

Showerloop is a solution to save water by recycling the water used in showering. Showerloop is an open source open hardware product. [1] Showerloop is a closed loop shower. [2] It recycles the used shower water. The aim of this product is to recycle the water used for showering and bring down environmental and economic cost. Most of resources we use are not endless but scarce and consumption rate is not sustainable. [3] This work is to propose control of Showerloop system.

1.1 Problem statement

The task is to design a control system for Showerloop. The control solution should be designed using electrical control element and new components according to requirement. Electrical scheme of the system should be made.

1.2 Significance of work

This work will provide an alternative control scheme for Showerloop. Showerloop prototype is controlled by Arduino mega. Showerloop.org was looking to make a custom made PCB using a microcontroller. [4]

From mechatronics perspective, this work will enhance author's understanding of system development and mechatronics design.

1.3 Objectives and goals

- Identifying the standards applicable to system
- Selecting the most suitable controller for the Showerloop
- Deliver a conceptual solution that is a control system
- Validate functionality of design by simulation

1.4 Scope of work

The scope of this work is to start with analysing the system, finding best suited electrical control device, developing control algorithm and developing a software application.

The mechanical and piping design is not a part of this thesis work. Parameters set by Showerloop.org related to filter efficiency, UV treatment requirements were not verified by the author as they were not directly related to the work. Proposing new components or suggesting changes in mechanism or usages is within the ambit of work. To draw piping and instrumentation diagrams remains Showerloop.org's responsibility. It is not within the ambit of this work.

2. Showerloop and other closed loop showers

2.1 Other closed loop showers

At the beginning of the work, other similar products were examined. There were few similar products already in existence. While examining these products overall working of product and techniques were studied. Focus of the study was not limited to control of shower's overall working was also studied to gain a better understanding of similar systems which proved very helpful later during the work. Though it was very tough to get information more than available on product websites.

Quench showers

This shower recommends use of soap and shampoo before entering in the recycling mode. As it is one of the main problems with recycling showers to clean water of oils, chemicals and substances which come from soaps and shampoos. Substances to be cleared out changes with the change of brand of soaps and shampoos and it makes the task very complicated. Quench showers recommend attending to cleaning needs for first few minutes and then enter in recycle mode (They call it quench mode). This shower supplies filtered, heated and pressured water to shower head. The operation of this shower is divided into two modes. In first mode user attend to cleaning needs, showering, shampooing, shaving, etc. Shower in this mode works like ordinary shower water you use down the drain.

In a second mode which is called auto mode, this shower uses four litres of water. This four litre of water is recirculated till shower is operating in shower mode. Quench shower has a provision to sanitise shower after the operation and a LED to indicate when it is time to refill the sanitizer bottle.

[5]



Figure 1. Quench shower tank and drain [6]

Cintep recycling shower

This shower also recommends using soap and shampoo first then only entering in recycle mode. After the soapy water has gone down the drain user is advised to let the reservoir fill, it fills with approximately four litres of water. After reservoir is filled user can enter in recycle mode. Shower water goes through the filters and then it goes through pasteurisation. Pasteurised water is diluted with 30% fresh water before coming to shower head again. The principle adopted in this shower is no sharing of water among users to minimise the risk of passing on bacteria, viruses or other pollutants from one user to another user. Cintep shower starts with three litres of fresh water and gets diluted with more fresh water at each cycle. This shower cannot be restarted until it is completely drained to make sure new user do not get water from old user. [7]

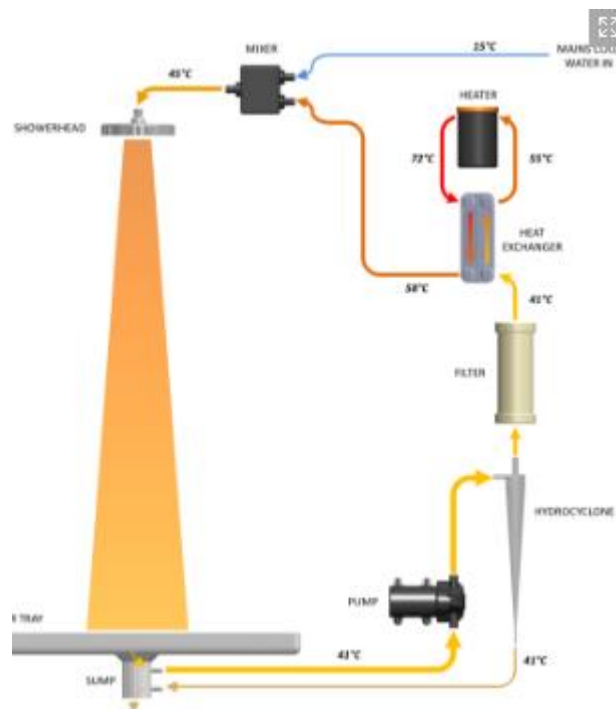


Figure2. Cintep shower block diagram [8]

Orbital Systems

Orbital Systems was founded in Malmo, Sweden in 2012. This shower has a heater which compensates for the temperature loss but needs a hot water and cold water connection. Heater on board alone is not meant to heat the bath water. On board, the heater is supposed to compensate for heat loss only. In this shower as well water is discarded after each shower and a new shower begins with a batch of fresh water. It is indicated by a LED when it is time to change capsule. [9]



Figure3. Orbital Shower [10]

2.2 SHOWERLOOP

Showerloop is a way of reducing the ecological footprint caused, by treating, heating, delivering and processing of water used for showering. The idea is simple, filter and re-circulate the water with a pump. Filtration is critical as it cleans water and the purpose of a shower is to get clean. [2]

It uses 10-liter water for one shower; a normal shower uses 6-10 litre/ min. Showerloop saves water and energy. Showerloop is made of transparent acrylic, steel or plastic pipe connectors and copper, drinking water hose, plastic or rubber tubing. Filter life is estimated at maximum two years. The operation of the filter is recommended for one year, but filter life depends on dirtiness and general habits of the user. UV lamp should work for thousands of hours and UV lamp can be replaced as easily as a bulb or CFL. [1]

System Description

Showerloop is modular regarding aesthetics, material selection and placement. Showerloop follows open license policy and business model. Which mean anyone is free to make Showerloop, modify it and contribute to Showerloop.org. It is necessary to include a description of control object in work so that reader knows what is being controlled.

Showerloop has a pump as can be seen in the figure which is used to pump water into showerhead as well as to pump water for backwash. Showerloop has total five valves.

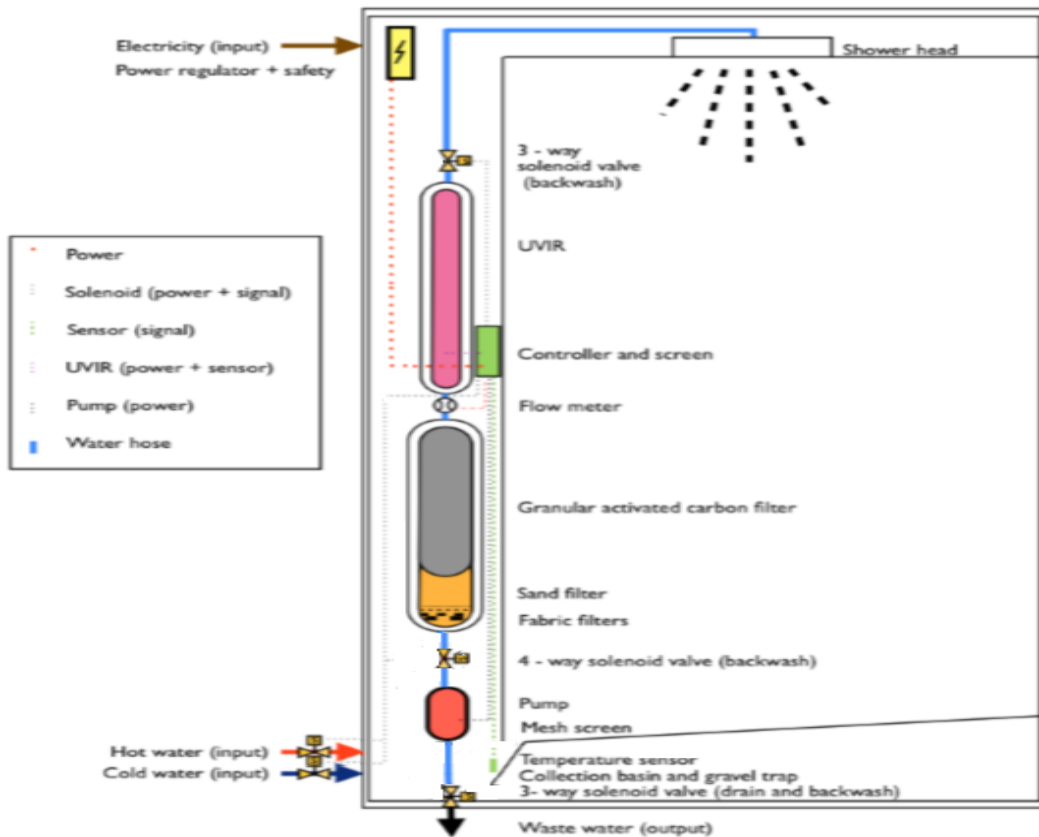


Figure 4. Scheme of automated prototype of Showerloop.org [2]

(Original figure from reference has been modified by author to demonstrate current scheme of Showerloop.org's prototype)

These are, hot water valve to serve as an inlet for hot water in the system, cold water valve to serve as an inlet for cold water in the system, three-way valve to provide two different paths to water for draining and backwashing the Showerloop, four-way valve above the pump to facilitate backwash and three-way valve between UVIR and showerhead. Showerloop has a filter housing which has two mediums to clean the water, sand filter and activated granular carbon filter. It has an ultraviolet irradiation reactor to kill microorganisms and purify water. Showerloop has a regular shower head. Details of components used by Showerloop.org are described below. Showerloop.org have two variants of Showerloop regarding control system used. In first variant Arduino Mega has been used to control Showerloop. This variant is automated. In second variant Ink bird-308 temperature controller have been used to control heating rest of the system runs manually. The second variant is fairly simple, manually controlled system.

Working of Showerloop

When user presses start button and choose a set temperature, hot water and cold water mixing starts inside the tank. Mixing of water happens naturally, and the mixer has not been used to perform hot water and cold water mixing. To achieve set temperature, a temperature controller has been used in the second variant of Showerloop. The temperature controller includes a temperature sensor as well. In a first variant which uses Arduino Mega to control Showerloop, a microprocessor program controls water heating and mixing process. As this water attains set temperature, it is pumped up the filter and passes through the UVIR and finally, reaches shower head. Water used in the shower goes down the drain and is collected back in the tank. During passing through filters, UVIR, pipes, shower head and in showering water temperature comes down. When this used water again reaches to tank, it is already below the set temperature. Then heater heats this water again to set temperature and same water recirculates through pump again.

Components used in Showerloop

The author describes components used in Showerloop by Showerloop.org.

Filter Capsule

The filter is a porous device to remove impurities from liquid or gas which passes through it. The filter used in this shower is up flowing pressurised filter. This kind of filters enables fast water recycling. As requirement is quick cleaning of water so that the same water can be cleaned and sent back to the shower head.

Up flow filters employ filtration from bottom up, using coarse to fine filtration. [3] Pressurised filter is when liquid is pumped through a filter with pressure through the pump. Pressurised filter technique is used in Showerloop for the sake of quick cleaning of water. Filter capsule of Showerloop consists of two different cleaning mediums, sand and granular activated carbon. Both mediums are in independent filter segments and are enclosed by the filter capsule.

Sand filter

Sand filters were used in a system for suspended solid separation. Sand filters were preferred because of abundance and low cost of sand. This sand filter is pressurised sand filter. Pressure filters are the filters where the pump is used to pressurise liquid before it can reach the filter. The pressurised sand filter in Showerloop removes particulate matter, turbidity, organic material and some microorganisms. [1]

Granular activated carbon filter

Activated carbon filter has been used because of its high porosity which results in a very high capacity of removing contaminants from water by absorption and adsorption.

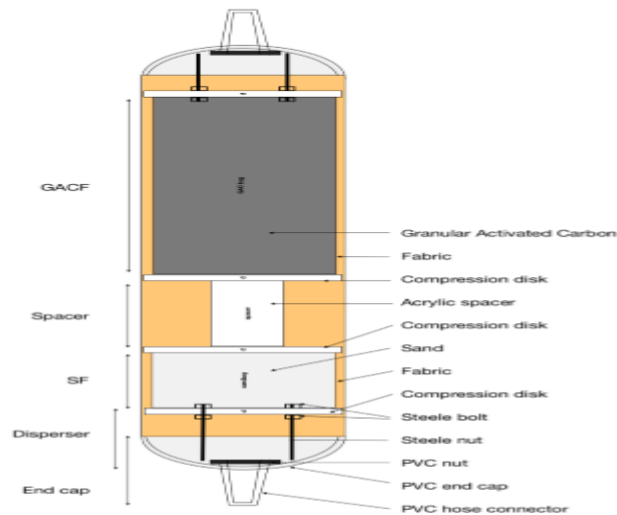


Figure 5. Filter in Showerloop [2]

Ultraviolet Irradiation reactors

Living organisms contain DNA which enables them to reproduce and function. Ultraviolet germicidal irradiation inflicts damage on the DNA of microorganisms. UV-C is also known as shortwave UV light. UV-C radiation can penetrate microorganism and to destroy the structure of DNA. Different species of bacteria require a different dosage of UV radiation to be inactivated. [2] A UVIR has been used in the system to clean water. [11]

UVIR units typically have one or many lamps which are installed above the stream of water, even submerged in some other. Microorganisms present in water gets exposed to a dose of UV-C radiation which destroys their DNA and kills them and effectively stops reproduction of microorganisms as well. To change the lamp, any tool is not required so the lamp can be changed very easily. UVIR from Purion has been used in Showerloop. Current showerloop.org website in the list of components suggests UV-C min 25 W can be used. The author has not verified efficiency (dose required to kill different microorganisms) of UVIR and minimum requirement to kill microorganisms as this is outside scope of work. The author took Purion UVIR in consideration used by Showerloop originally. Inside the reactor, a UV lamp is situated enclosed in a UV-C transparent quartz pipe. [12] This component have not been selected by the author.

Heater

Electric heating element booster iron AC 220V 2000W has been used in original Showerloop prototype and author recommend continuing to use it as a heating element. On board, the heater is not supposed to heat the water all by itself rather it is to maintain water temperature. [13]

Outlet thermostat controller

INK-Bird ITC308 has been used in the original prototype design of Showerloop. This is a plug and plays device. It has a dual LED display which can display temperature in centigrade and Fahrenheit. It has a temperature sensor as well. This controller has been used in the second variant of Showerloop which is not fully automated. [14]

Screen filter: Showerloop has a filter like the one in the kitchen sink to remove objects and to protect the pump. [1]

Micro-fiber/geo-textile: It help keep the filtrate materials but also works like the mesh filter. [1]

Other main parts of Showerloop are a tank, shower head. Heating element and pump. In tank hot and cold water from houses' plumbing network mixes.

Solenoid valves used by Showerloop.org are plastic solenoid valves. Working temperature of these valves is 1°C to 75°C. It is a unidirectional valve. This valve operates on 6-12 V DC. This valve is normally closed and opens on applying voltage. This is a very low-cost valve. These valves require 6-12 V DC to operate. It is required to make 6-12 V DC supply available.

Conclusion and tasks to be solved

Variant which runs on Arduino and is automated is of interest for the work. A prototype of this variant of Showerloop runs on Arduino. Arduino is a combination of two things: a series of circuit boards, and a programming environment and a set of code libraries. If the application is very low volume and high margin (like a specialised lab instrument or machine for a factory), then the disadvantage of the additional unit cost of the Arduino stands. High-volume, low-margin, and low customization products, for which a mass-produced electronics board would be cheaper. So making a custom board is the road to future when shower loop is produced in considerable quantities. Showerloop is highly modular and open source open hardware product. People who would want to do it themselves may still choose the controller of their choice.

An Arduino is built to do many different things, and thus has many different capabilities. These capabilities come at a cost. Better to do prototype using an Arduino, then get a custom-made board that does exactly what you want it to do and no more. Which is exactly what Showerloop was considering.

Cons for Arduino vs. custom developed board:

- higher cost (If only MCU on PCB it should bring the cost down a little, it will be significant only for large quantities)
- the lower performance-to-cost ratio
- less flexible regarding integrated peripherals
- more difficult to integrate (mechanical and electrically)
- supply chain geared towards consumers rather than manufacturers
- the form factor is unsuitable

- does not have a proper hardware design for pogo pin testing
- User do not have full control over design
- Arduino restricts the use of hardware capabilities to full limits.
- Dedicated tools have more perfection and precision in their works.
- Design custom and optimised (cost, size, etc.) board including the sensors and control gives robustness to design.

So if you are going to mass produce a product, it's quite clear that making a custom board is better than using Arduino mega.

Arduino has a lot of pins and features that might be left unused if one wants to make only one specific machine. It is understandable left out pins and sockets do not hurt financially or hinder in achieving object but it is a design flaw. Many start-ups build a product based on Arduino. Arduino has been successfully used in small volume commercial products. If one want to make a product that uses Arduino board inside of it, it is possible according to Arduino website.

In conclusion, Showerloop can be sold with Arduino but making your control board is favorable to switch to higher volume production. Controller other than microprocessors should also be considered.

Requirement analysis for hardware

As the Showerloop is already in existence requirements were largely predefined for components. Where the ever requirement for a component selection was predefined in Showerloop, they were taken as it is. Requirements for cleaning of water, like sand size, mesh size and granular carbon size were not verified. Requirements outside the ambit of control i.e. this work, defined by Showerloop.org for components have not been verified during this work. Some suggestions have been made for replacing components where the need arose because of change in power supply from 12 V to 24 V and controller. As Showerloop originally runs on onboard 12 V DC supply. The author suggested components for a solution with 24 V DC supply as work was being done on 24 VDC.

Requirement analysis for software

Showerloop should be able to be controlled automatically while allowing user enough freedom to change and interfere. The user should be provided buttons to start and stop the shower. Under automatic control user should be able to select the temperature of water, showering time and whether he wants to shower with fresh water or recycled water. This should be with keys/switches provided. In manual control mode. There should be a provision in manual mode to empty tank if the user wishes to do so in between the shower. The user should be able to get alarms when it is time to change UVIR. All the features are available in Showerloop controlled by Arduino and should be kept in work done by the author.

Requirements for standards

Showerloop is still in design and testing phase, and it was required to find applicable standards so that they can be implemented in the design itself. Following standards will make it easier to gain entry in specific markets.

Deliverables and methodology

Following outcomes are expected of this work,

- Finding applicable standard to the system
- Study of electrical control components so that suitable component can be selected.
- To deliver a conceptual control system, testing it on real hardware remains Showerloop.org's responsibility.
- An automation system which allows end user enough possibility to dictate to enjoy showering experience.
- Electrical schemes for technical use and manual for the end user.

3. THEORETICAL BACKGROUND

3.1 Contaminants in shower water

Contaminants in water used in showering can vary from skin cells, sweat, urine, faeces, dust, hair, chemicals coming from deodorants and beauty and personal care products. Soap and shampoo during shower also bring in additional chemicals in the water to clean. These pollutants affect water's odour, colour and quality.

Variable	Unit	Average concentration according to Lehr	Average concentration according to Almeida. (The value range found in the literature is given in parenthesis).	Average concentration according to Eriksson
Volume	l	-	42.3(32-06)	-
BOD	mg/l	216		-
COD	mg/l	424	221 (-)	424
PO ₄ -P (Phosphate as P)	mg/l	1,63	19.2 (1-2)	1,63
NH ₃ -H (Ammonia as N)	mg/l	1,56	6.3 (0.3-0.4)	2,1.56,1.2
Turbidity	NTU	92	-	28-96
Total solids	mg/l	631	-	631
Total suspended solids	mg/l	-	200 (119-120)	120-200
pH	-	7,6	-	7,6
Inorganic carbon	-	-	-	26
Total coliforms	/100 ml	-	6 x 10 ⁶	(70- 6x10 ⁶)
Faecal coliforms	-	-	-	(1- 6x10 ³)
Faecal Steeple/toed	-	-	-	(l - 7x10 ⁴)

Table 1. Contaminants in shower water [2]

(Author of reference give in table cited data from Lehr and Eriksson, both of them cited data originally from Surendran and Wheatley, 1998)

Above table shows usual contaminants found in shower water. These are usual contaminants, but actual contaminants depend on users' habits, lifestyle, general habits and the environment he lived in before taking a shower.

3.2 Possible cleaning technologies

There are different water cleaning technologies available nanofiltration and pasteurisation techniques have been applied by competitors of Showerloop. Showerloop chooses sand filtration because of easy availability of sand. Granular activated carbon filter and ultraviolet irradiation were used because of ease of implementation and relatively low cost of the granular activated carbon filter. The combination of sand filtration, granular activated carbon filtration and ultraviolet irradiation treatment provides a

simple solution to the problem. Chemical technologies are not fast enough for the requirement of the system. [2]

Other viable technologies are chlorination flocculation, desalination, dilution, pasteurisation among others. Other technologies can be applied to clean water and effect of technology change on control task will depend on the new technology chosen.

Filter	Considerations	Working principal	Safety considerations	Energy intensity (relative to each other)	Potential for environmental/health risks	Low operating costs	Easy to build	Components moderately available	Real-time	Contaminates
GAC filter		Physical/Chemical	Safe to drink in low concentration	Low	Low	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Sand filter		Physical		Low	Low	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Fabric filter		Physical		Low	Low	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Desalination		Physical	High pressure / temp	High	Medium - high	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Chlorine		Chemical	Concentrate is toxic	Low	Medium - high	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Bio-filter		Biological	Unknown	Low	Low - medium	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Flocculation		Chemical	Coagulants must be removed	Low	Low - medium	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Membrane filter		Physical		High	Low	Unknown	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ozone		Physical/Chemical	Exposure is toxic	Medium	Medium	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Unknown	<input checked="" type="checkbox"/>
Ultraviolet germicidal irradiation		Physical	Exposure is dangerous	Medium	Low	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Iodine		Chemical		Low	Low - medium	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Unknown	<input checked="" type="checkbox"/>

Table 2. Water cleaning technologies [2]

4. STANDARDS APPLICABLE

Shower loop is filtration, purification and recycling system for used shower water. The product is in the development phase and plans to go to business. As Showerloop.org aim to cover as wide as possible market studying the standards applied in different countries will be helpful in modifications required according to different geographical locations or simply concentrating on most suitable markets regarding technology already existing in design. Standards applied on the product can be voluntary or obligatory.

Obligatory standards are standards that are compulsory and are usually related to the safety of human being. Different legal compulsions have to be taken into account as they enforce standard by law author do not plan to go into detail as this is out of the ambit of this work.

Voluntary Standards are standards which are followed voluntarily and do not have any compulsive force behind them.

Sustainability parameters should be proved with facts as the product claim of saving water and energy. Extended producer responsibility is another important issue to check, and this varies greatly from country to country. For a startup ideal situation is no extended producer responsibility.

How to overcome with one single design for different standards in different countries is a problem which needs to be looked into as Showerloop plan to go to market in different countries.

Different countries have different standards for safety, control of chemicals, producer responsibility and restriction of hazardous substances, environment, etc. ISO is widely accepted, but national standards and legalisations differ. It is a producer's nightmare to develop and design the product according to every new market.

The need arises to compare the different standards in different countries, legal frameworks and the treaties that allow or enforce same standards in a region or some countries. It is important to study some of treaties or WTO frameworks.

Life cycle assessment of the shower loop is also required to find the impact of chemicals, hazardous substances, and extended producer responsibility and in finding out if it fulfils particular safety and environmental standards. Life cycle assessment also provides Showerloop with a documented proof of energy and water savings which are main goal of the product.

Standards applicable in France were considered as Showerloop.org see it as a prospective market. Germany is a market of interest for showerloop.org because of being a relatively populous country in Europe, so it presents the possibility of volume in sales. Estonia, showerloop.org sees as a prospective market because of its proximity to Finland where the company is based. Showerloop.org was founded, and it is located in Finland and looks at Finland as a natural market. India is facing a historic water shortage because of irregular monsoon, ever decreasing water bed and huge population, so it is also considered as a prospective market. All other countries of interest are in the European Union. So the main comparison remains in between European standards and Indian standards.

Standards of following bodies can be looked into;

European Committee for Standardization (CEN)

European Committee for Electrotechnical Standardization (CENELEC)

International Electrotechnical Commission (IEC)

Standard

A standard is a document that defines guidelines, requirements, specifications or characteristics that can be used to make sure that products, materials and processes are fit for their purpose.

Directive

Usually, a document that serves to direct, guide and impel toward an action or goal, especially an authoritative instrument issued by a high-level body or official.

[15]

Standards applicable to shower loop can be divided into two major categories,

Obligatory Standards

Standards for water quality and human safety are obligatory. In principle standards other than these two mentioned are voluntary in nature

Voluntary Standards

All the standards are voluntary until unless they are made binding by law. Water quality, human safety are obligatory.

4.1 Standards applicable to water

Water standards are really important to be looked into for this work. As water is categorised in all countries under consideration as water for human consumption which needs to fulfil drinking water standards. [16] Standards are laid down for equipment which is installed to water supply inside buildings, the material being used in this equipment, to prevent backflow from this equipment. Though in daily life we do not necessarily look upon the municipal water as drinking water they have to fulfil the drinking water standards [17] and any equipment being installed which comes in touch of this water have to maintain standards to ensure the water quality remains potable.

Though U.S. Army began researching on closed loop showers and developed a revised quality criteria for recycled shower water. They categorised it under non-potable reuse. This work was for field shower to develop appropriate technologies and health criteria. [18]

Water supplied for human consumption have to fulfil drinking water criteria, and it is one of the challenges for Showerloop.

European drinking water standard

Council Directive 98/83/EC [16] on the quality of water intended for human consumption sets out parameters and values for water to fulfil if water is for human consumption. This Directive makes it compulsory for member states not to set parameters below than parameters set in this directive. Values in annexe I are largely based on world health organisation's "Guidelines on drinking water quality." [19]

Parameter	Parametric value (number/100 ml)
Escherichia coli (E coli)	0
Enterococci	0

Table 3. Biological parameter requirement in EU drinking water directive [19]

(Parameters have been checked by Showerloop.org but were not achieved) [2]

Parameters must be checked listed in this directive. Which are,

Substance	Already tested in Showerloop
Aluminum	yes
Ammonium	Need to be tested
Colour	Need to be tested
Conductivity	Need to be tested
Clostridium perfringens (including spores)	Need to be tested
Hydrogen ion concentration	Need to be tested
Iron	Need to be tested
Nitrite	Need to be tested
Odour	Need to be tested
Pseudomonas aeruginosa	Need to be tested
Taste	Need to be tested
Colony count 22°C and 37°C	Need to be tested
Coliform Bacteria	Need to be tested
Turbidity	Yes

Table 4. EU Drinking water directive requirements

France, Germany, Finland and Estonia all four are a member of CEN and bound to follow standards set by CEN. If a particular standard is set by CEN and then members of European Union, have to adopt the same standard and declare it as a national standard.

Indian drinking water standard

Drinking water standard applied in India is IS 10500:2012 drinking water Specification (second revision). This specification accepts lower parameters in the absence of alternate source. It could be beneficial for Showerloop as in drought-hit areas it needs to fulfil lower standards. A very distinct feature of this standard from EU drinking water directive is that this standard sets parameters for pesticide residues as well. In India, pesticides are widely used, and they later mix with ground water. The limit for specific pesticides has been set in this directive. In shower water pesticides can be added while taking a shower in farming areas given their wide use in rural India but for the non-farming user, pesticides will be largely absent, so these parameters do not affect Showerloop in that situation. [20]

4.2 Standards applicable to Showerloop

Standards applied to the product, its parts and components, standards applicable to backflow, human safety and sustainability all are very important for the product to gain entry in any particular market.

Some standards of interest are listed below:

EVS-EN 14898:2006+A1:2007 Water conditioning equipment inside buildings- Active media filters- Requirement for performance, safety and testing [21]

IS11743 Guide on Human Safety in Design, Manufacture, Use and Maintenance of Electronic equipment. [Indian standard] [22]

IEC 60335-2-105, Household and similar electrical appliances safety- Part 2-105: Particular requirements for multifunctional shower cabinets.[23]

EVS-EN 15200:2007, sanitary appliances-Multi function shower cabinets [24]

CE marking

CE marking demonstrates compliance with EU legislation (such as New Approach Directives). It is to be applied by the manufacturer or his/her representative. Some directives require conformity assessment by a neutral third party, called a "notified body" before the marking can be applied. It is for products which pose a higher security risk. [25]

By applying the CE marking a manufacturer declares on his/her sole responsibility that the product meets all the legal requirements and can thus be placed on the EEA market. It should be noted that the CE marking is not a quality mark, nor does it indicate that the product was made in Europe. As such, it is not intended for the end consumer

5. SELECTION OF CONTROLLER

5.1 SELECTION OF MICROCONTROLLER

A microcontroller unit can be seen as a small computer on integrated circuit. A microcontroller may contain one or more CPU along with memory.

Work was started by studying electrical control components. First microprocessors were investigated to control Showerloop. Many different microcontrollers were taken into consideration.

Both microprocessor chip and development board options were considered as a prospective tool to the solution. Development boards provided a fast and easy solution to the problem, so they were considered an advantage over microprocessor chips. As first a proof of concept can be developed then it was possible to move to making a custom made PCB. On the other hand, microprocessor chips were considered as a direct step towards building a custom made printed circuit board. An integrated programmer/ debugger and no additional software needed were considered as an advantage.

Development boards considered were:

Curiosity PIC32MX470

Curiosity PIC32MX470 have an integrated programmer/ debugger. Having an integrated programmer/ debugger was considered an advantage as it brings down the cost of development. This board can support audio, USB and Bluetooth applications. This contains LEDs, RGB LED and a switch. Every board have two microbus expansion sockets from Microelectronika, I/O expansion header and microchip X32 header. [25]

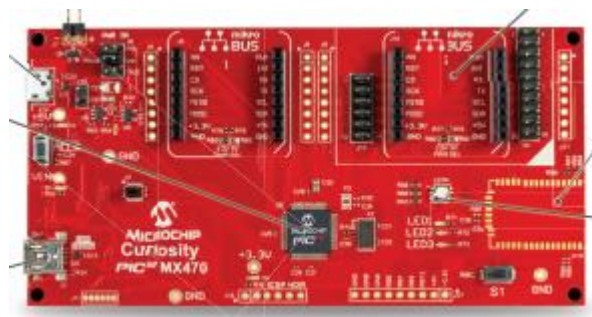


Figure 6. Curiosity PIC32MX470 [26]

Curiosity HPC development board

Curiosity HPC also has integrated programmer/ debugger like Curiosity PICMX470 and needed no additional hardware to the program. Interface electronic design was required if this board is selected.

External connections and curiosity's layout offer access to core independent peripherals. These core independent peripherals make it possible to integrate various system functions on a single microcontroller unit. Curiosity development board offers several options for user interface and a potentiometer on the board. Accessory boards are available via Microelectronika Microbus interface footprints. [27]



Figure 7. Curiosity HPC development board [27]

EXP-MSP430FR4133 Launchpad

EXP-MSP430FR4133 is an evaluation module for microcontroller MSP430FR4133. It contains onboard emulation for programming and debugging. The board features LED, buttons and a liquid crystal display. Booster packs can be plugged in, in plugin module headers. Features like wireless connectivity and graphical display can be added easily. It also has a thermometer application using an on-chip temperature sensor. Temperature is displayed on LCD in degrees Fahrenheit or Celsius. Code Composer Studio free edition with GCC compiler can be used. [28]



Figure 8. EXP-MSP430FR4133 Launchpad [28]

MSP430FR6989

It has supply voltage range 1.8 V to 3.6 V. MSP430 ultra-low-power (ULP) FRAM platform combines uniquely embedded FRAM with ultra-low-power system architecture, allowing better performance at lesser energy budget. FRAM technology combines the flexibility, speed and endurance of SRAM with the reliability and stability of flash at much lower power. [29]

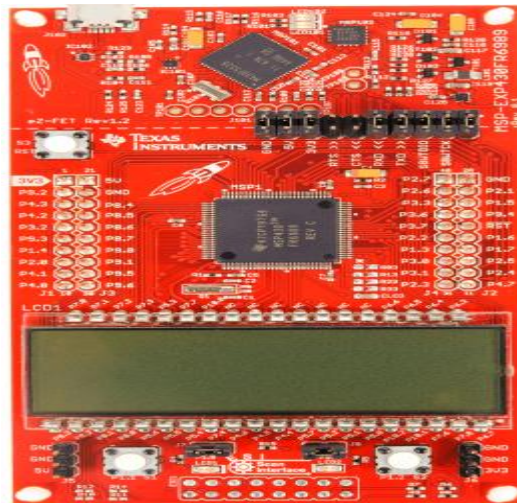


Figure 9. MSP430FR6989 [30]

Simplelink CC2650 wireless MCU

It has 32 bit ARM Cortex M3. CC2650 Launchpad kit supports programming and debugging from code composer studio and IAR Embedded Workbench integrated development environments. This has an ultra-low power sensor controller which works for interfacing external sensors and collects digital and analogue data autonomously while rest of the system is in sleep mode. It has possibility of connecting with Bluetooth.project.0 which is Bluetooth Smart peripheral application. This connection allows control of the Launchpad kit's LEDs from TI simplelink sensor Tag kit ios app or compatible devices supporting Bluetooth low energy connectivity. It allows quick interfacing to other evaluation modules and Booster Pack plugin modules.

Internet of things can be developed using TI BLE-Stack Software Development Kit which has Bluetooth 4.1 certified software stack. [31]



Figure 10. Simplelink CC2650 wireless MCU [31]

Microprocessors considered were:

ATMEGA 2560

Complete microcontroller based electronic design was required with this microcontroller. Additional hardware was needed to program the microcontroller. It is an 8-bit AVR RISC-based microcontroller. It is possible to use capacitive touch buttons, sliders and wheels with Qtouch library support. It can work in the temperature range of -40°C to 80°C . [32]

PIC18F65J50

This MCU has various ports for connectivity. This MCU has large amounts of RAM as well as enhanced flash program memory. Its memory features make MCU suitable for embedded control and monitoring applications which require connection to PC via USB for data upload download as well as for firmware updates. [33]

PIC18F45K22

This microprocessor had a C language compiler and optimised architecture/ instruction set. It provides priority levels for interrupts. It has in circuit serial programming, and in circuit serial debug. [34]

No.	1	2	3	4	5	7	8	9
Product	ATMEGA 2560	PIC18F 65J50	PIC18F 45K22	Curiosity PIC32MX 470	Curiosity HPC Development Board	MSP430 FR4133 LaunchPad Development Kit	MSP430 FR6989 LaunchPad Development Kit	SimpleLink™ CC2650 Wireless MCU LaunchPad™ Kit
CPU	8 bit	8 bit	8 bit	32 bit	8 bit	16 bit	16 bit	32 bit
Processor or Dev board	Microcontroller	Microcontroller	Microcontroller	Development board	Development board	Development board	Development board	Development board
Additional features	Not applicable	Not applicable	Not applicable	Microelectronics bus support	Microelectronics bus support	Built-in LCD display	Built-in LCD display	LEDs on board
Supply voltage	1.8 to 5.5 V	2 to 3.6 V	1.8 to 5.5 V	5 V	5V	5 V	5 V	5V
Debugger	External programmer required (JTAG)	External programmer required	External programmer required	Integrated programmer/debugger	Integrated programmer/debugger	Integrated programmer/debugger	Integrated programmer/debugger	Integrated programmer/debugger
Software (Free/Paid)	<u>Atmel studio (free software)/ C language</u>	C compiler	C compiler	MPLAB X IDE with XC C Compiler (free edition with limitations)	MPLAB X IDE with XC C Compiler (free edition with limitations)	Code composer studio free edition with GCC compiler	Code composer studio free edition with GCC compiler	Code composer studio free edition with GCC compiler
Hardware design	Complete electronic design required	Complete electronic design required	Complete electronic design required	Interface electronic design required	Interface electronic design required	Interface electronic design required	Interface electronic design required	Interface electronic design required

Table 5. Microprocessor comparison table

Discussion

Pin count, I/O and analog inputs are not shown in table number 5 as all microprocessors and development board fulfill these requirements. Low cost was the main factor in consideration. Built in LCD and in-circuit debuggers were considered a must have in development boards as they save the cost of add-on modules and extra hardware. Availability of integrated programmer/ debugger was

also considered. Availability of add-on Bluetooth/Wi-Fi modules was considered as they were considered advantage for future application development. Hardware development time and availability of enough code examples were another vital factors in consideration. For microchip products, it was possible for an author to get licensed programmer/ debugger. Another advantage of using microchip products was code examples are widely available on the internet and it is very easy to find support for the microchip. MSP is a low power device, and it is the best advantage of this product. But to acquire MSP product shipping charges were considerable in comparison to product cost. Texas instrument products provided easy options for communication. Author favored microchip devices because of easy availability, possibility to get programmer/ debugger for no extra cost and easily accessible support.

5.2 SELECTION OF PLC

Programmable Logic Controller

Programmable logic controllers are widely used in home automation. PLC was first used to provide easily programmable controllers as a replacement to hard-wired relays. PLCs can survive harsh environmental conditions like heat, dust moisture and cold.

PLC can read signals from field devices. These field devices can be sensors or switches etc. Inputs can be both digital and analogue signals.

Siemens LOGO logic module

Siemens logo logic module was chosen for the control of Showerloop. Siemens LOGO logic module has eight input ports I₁- I₈. The logic module has four output ports Q₁-Q₂. Project requirement was of six output ports so output module 6ED1055-1MB00-0BA2 would be required. [35]

As HMI was not used for user-machine interface, it was considered an advantage that LOGO gives optical emphasis on alarms. Backlight colour can be selected for alarms as amber or red. For the same reason, ease of operation of LOGO was also considered an advantage. Showerloop is meant to be installed inside homes. LOGO has certification for installation in residential areas. Temperature range of module is -20°C to 55° C.

Availability of LOGO logic module in university lab was also a factor behind the selection of controller.

Though some outputs available on logic module were not sufficient, outputs were checked on simulation. Product number of LOGO logic module is 6ED10521MD000BA8. Terms LOGO0BA8 and logic module refer to the same product in work and have been used interchangeably in work.

6ED1055-1MB00-0BA2 is additional I/O module compatible with LOGO0BA8. [36] This I/O module

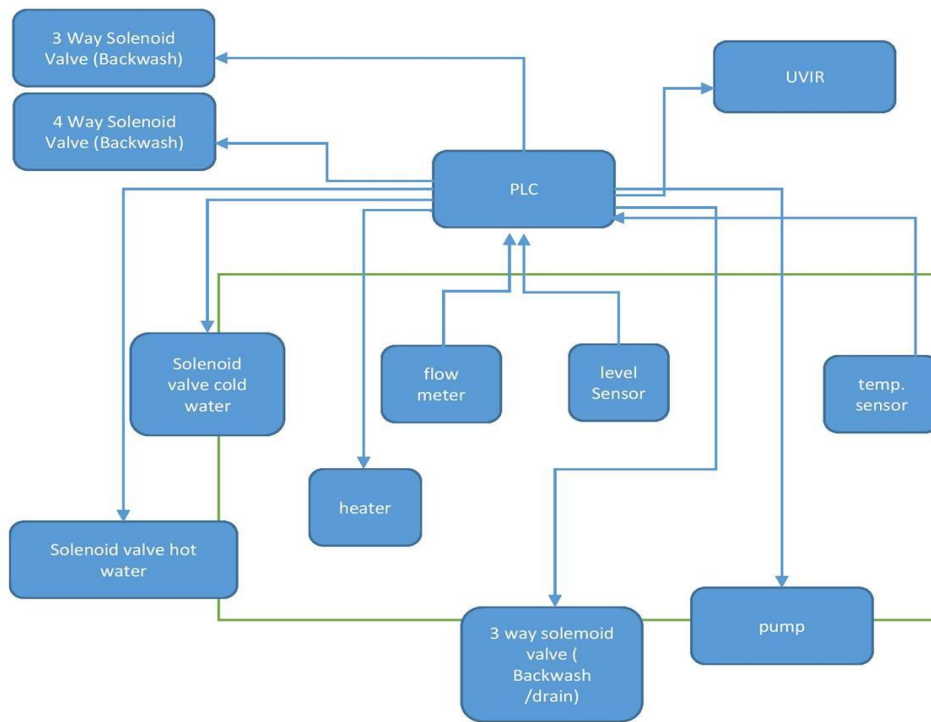


Figure 11. Showerloop controlled via PLC

can be used for hardware testing of the system. Display of logo provided the possibility of a simple user interface. Display and Keys of PLC were able to provide user possibility to see the status of the system and interact with it.

Siemens LOGO power module

Power module 6EP13321SH52 was used to supply 24 V DC voltage. This power supply module can be supplied with 85 to 264 V AC or 110 to 310 V DC. This module provides us with a soft start. It has rated current value 4 A. [37] This module was not connected mechanically with LOGO0Ba8. The module was mounted on same DIN rail as PLC, and 24 volt supply was provided to LOGO0BA8.

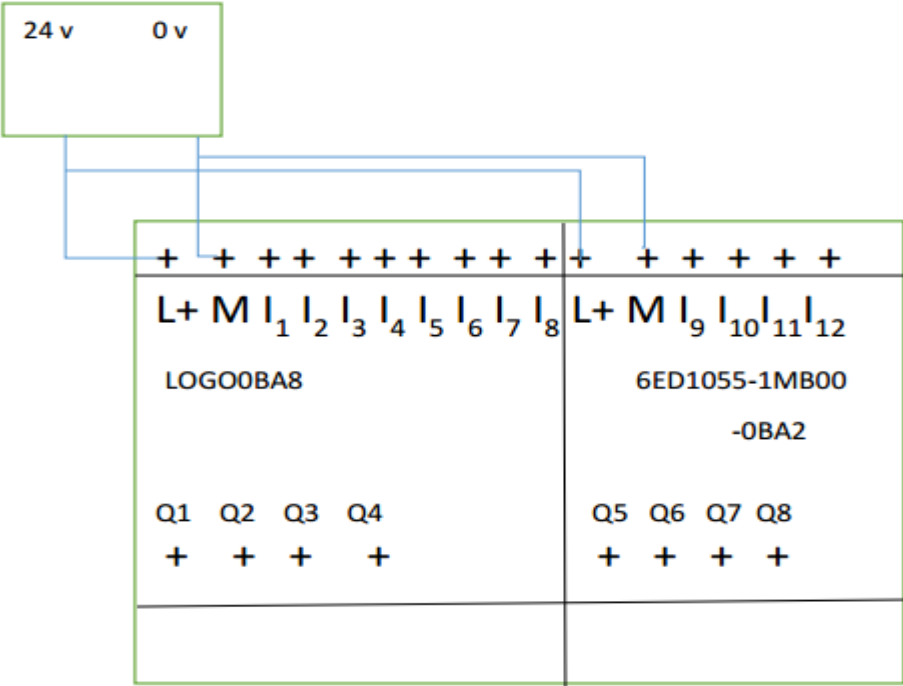


Figure 12. Scheme of PLC modules

A network cable is needed to connect LOGO to PC with Ethernet interface. To program LOGO from PC with Ethernet interface a TCP/IP connection should be established. IP addresses of both devices LOGO and PC must match so that they can communicate with each other. [38] This connection is needed to download the program in LOGO0BA8.

MAC address is divided into two parts first part is fixed and identifies the manufacturer. The second part is unique and serves to differentiate between various ethernet devices. Factory assigned MAC address is printed over LOGO 0BA8.

Why choose PLC over microcontroller

If the author chooses to select microcontroller as a controller for the system, then interface electronics need to be designed. If PLC is used, the electrical design is comparatively simpler. PLC can be integrated with rest of the system much easily. Microprocessor are economical in case of the mass production cost of components, programmer/debugger, development, interface hardware is spread over a huge number of products and cost of components is lower. In the case of Showerloop product is not being mass produced at this moments and as it is an open source and open hardware product enthusiasts may build single pieces. In that situation, PLC as a controller proves much simpler to use. As for Arduino still some interface electronics is required, in the case of PLC electrical design is not so complicated.

Availability of LOGO0BA8 in university laboratory was a factor in choosing this particular PLC over any other manufacturer.

6. CONTROL SYSTEM DESIGN

The author is designing a control system for the Showerloop. In figure 13 hydrodynamic scheme of control objective is shown. The scheme in figure 14 was proposed by Showerloop as a future work to be implemented. Specific components and controller, electrical schemes were not proposed by Showerloop.org to implement scheme shown in figure 14. The author has proposed controller in chapter 5, electrical scheme and components in Chapter 6 and developed a software described in chapter 7 to control. In figure 14 level sensor was not part of the scheme proposed by Showerloop.org author have added it. Authors work is limited to provide a conceptual solution and testing it with real hardware and finalizing remains Showerloop.org's responsibility.

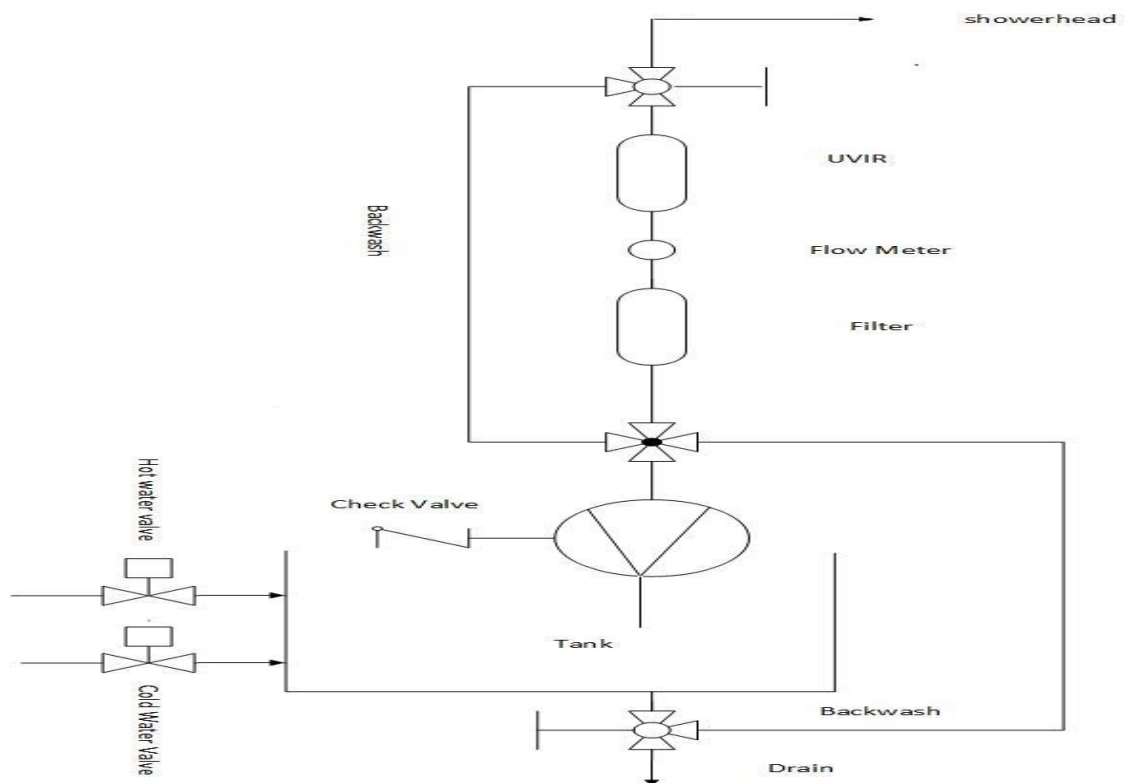


Figure 13. Hydrodynamic Scheme of Showerloop

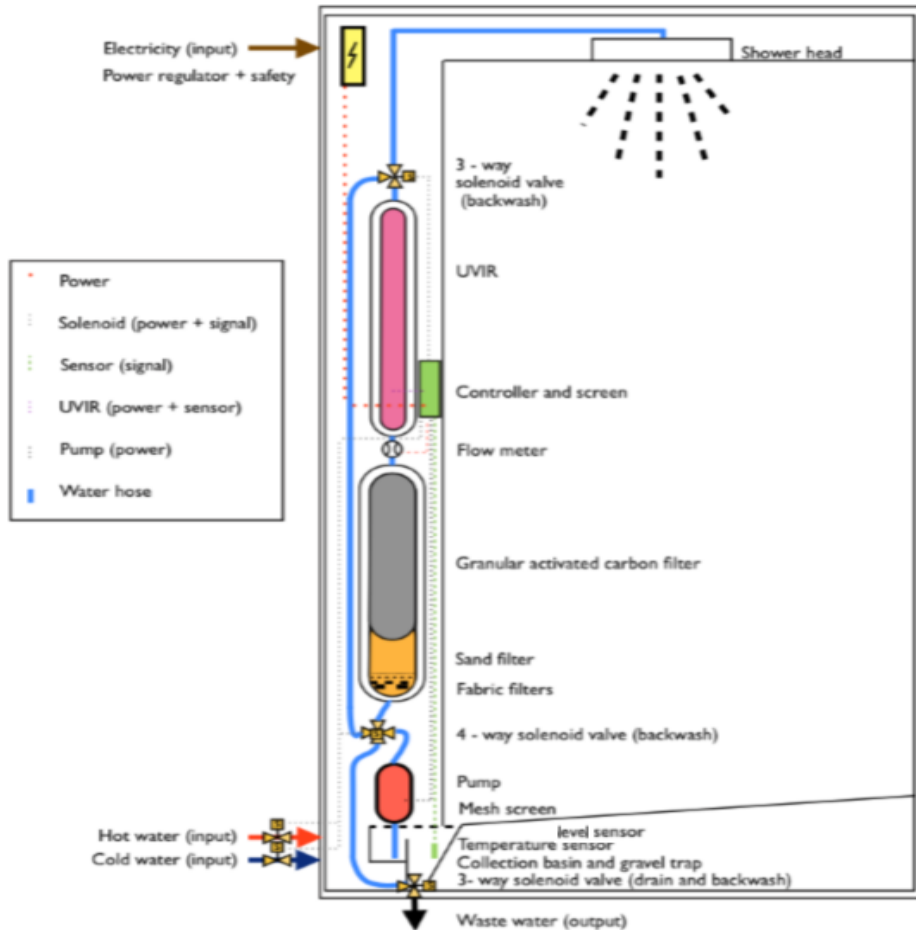


Figure 14. Scheme of Showerloop with backwash [2]

6.1 Electrical scheme of the system

Wiring has been done using SEE Electrical software. It is an electrical CAD package which was used to draw the wiring diagram for this work. Though some components were used on 12 V DC in Showerloop, I have 24 V DC supply available, so I suggested components which use 24 VDC. Logo logic module runs on 24 V DC. 24 V DC has been provided by power module. Though the author has used 24 V supply, it is suggested to use 12 V DC in the final product as Showerloop have other variants of Showerloop as well which run on 12 V DC and if 12 V DC supply is selected same products can be ordered in bulk and can be used in different variants of Showerloop. It will be much economical for Showerloop.org later.

Two push buttons and one toggle button has been used. Toggle button has been used to enable/disable machine, and it is connected to I₅. Start button (green push button) is connected to I₁ and stop push button (red push button) is connected to I₂. The signal from the level sensor is connected to I₈. The signal from the temperature sensor is connected to I₇. Flow meter also runs on 24 V DC and is connected to 24 V DC power supply.

Input connections

No	INPUT	SIGNAL FROM	SIGNAL TYPE
1	I ₁	Start Pushbutton	Discrete
2	I ₂	Stop Pushbutton	Discrete
3	I ₃	Emergency	Discrete
4	I ₄	Flow meter	Analog
5	I ₅	Enable/ Disable	Discrete
6	I ₆		
7	I ₇	Temp sensor	Analog
8	I ₈	Level meter	Analog

Table 6. Input connections

Output connections

No	OUTPUT PORT	SIGNAL TO
1	Q ₁	Pump
2	Q ₂	Valves
3	Q ₃	Hot water valve
4	Q ₄	Cold water valve
5	Q ₅	Drain/ backwash
6	Q ₆	Heater
7	Q ₇	UVIR

Table 7. Output connections

As described in table Pump is connected to Q₁. Four-way valve and the valve between pump and filter are connected to output Q₂. Hot water valve and cold water valve are connected to Q₃ and Q₄ respectively. Three-way valve for drain and backwash is connected to output Q₅ on I/O module. The heater is also connected to the output of I/O module that is Q₆.

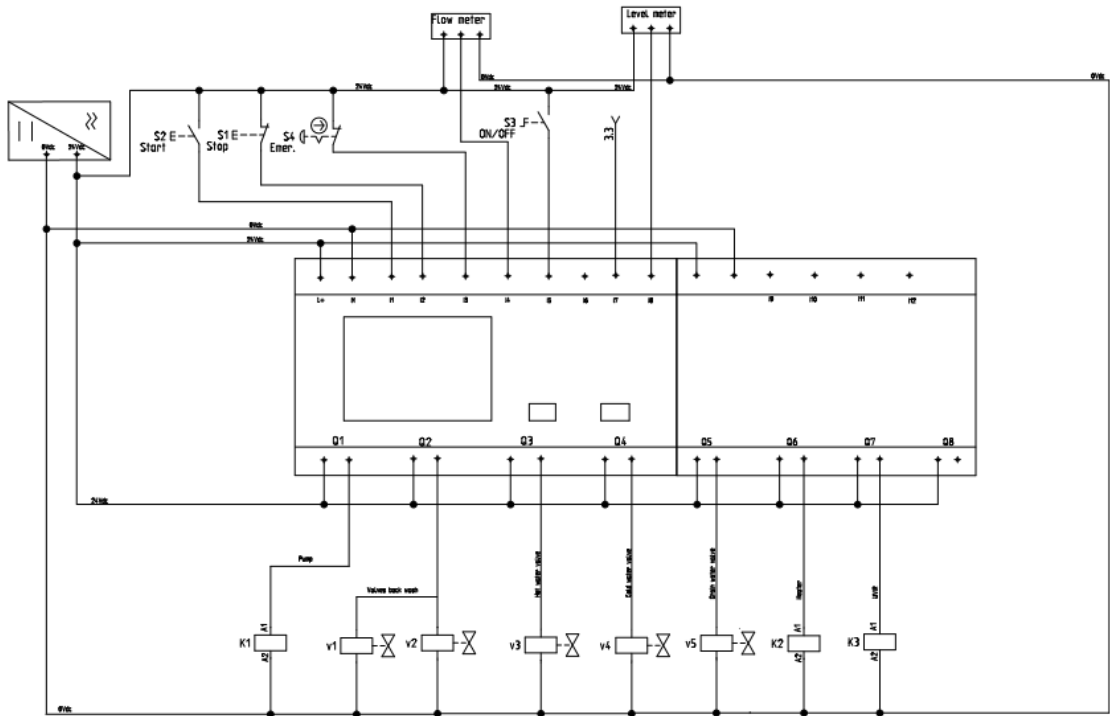


Figure 15. Electrical scheme of Showerloop

6.2 SYSTEM IMPLEMENTATION

Component selection

As LOGO0BA8 was selected as the controller interface electronics needed to be replaced with electrical components. Below mentioned components are suggested to be used. These components were considered a part of the system for making software. UVIR has not been selected by the author it is the same UVIR used in original Showerloop prototype. Filter have not been designed and suggested by the author they are same filters being used in Showerloop prototype. The heating element has not been suggested by the author, the same heating element as Showerloop.org's prototype has been used by the author. Showerloop.org is working with improving their current scheme so the scheme was not available on time of writing this work. Showerloop.org is working on piping and instrumentation scheme and it is out of work ambit of author. Check valves, and other components needed to implement piping are not being suggested by the author it remains Showerloop.org's responsibility to select them along with drafting piping and instrumentation diagrams.

Components described below are author's suggestion for implementing control with LOGO0BA8 and enable backwash.

Solenoid valves are operated electromechanically. If the valve is a three-way valve, then outflow gets switched between the two outlets.

Author has solved control task using below components. These valves enable implementation of backwash.

Three-way valves

This three-way solenoid valve when not energised gives way to one path of water and when energised gives way to another path of water. However, in the reference smaller size of the valve (smaller than in Showerloop prototype) is mentioned but it is possible to order different sizes of valves. As Showerloop is open source open hardware every enthusiast or professional might choose different sizes of pipes or water hose. This valve operates on 24 VDC.[39]



Figure 16. Three-way valve [39]

Four-way Valve

This four-way valve is available in different sizes. Appendix 3 can be referred for different sizes. This solenoid valve also opens different paths when energised and de-energized. This characteristic of valve enables backwash in the system. [4]



Figure 17. Four-way valve [40]

Pump

The pump which runs on 220 V AC can be used. Other parameters of the pump are decided by Showerloop.org and are not verified again and proved by the author. A brushless membrane pump can be used. Flow rate can be 12 l/min, pressure minimum 3 bar. A 90 W pump will be suitable.

Interface relay

Two P-16-1P- 24 VDC relay from relpol can be used to wire pump and UVIR with PLC. [41]

Temperature sensor

A PT100 temperature sensor can be used to measure water temperature in the tank. This sensor can be fixed near the bottom of the tank. Connection of temperature sensor can be seen in figure 19.



Figure 18. PT100 [42]

Transmitter

Transmitter helps to convert signal from PT100 to 0-10V signal which is connected to PLC. PT100 provides signal 0-5 V which is converted to 0-10 V before sending to PLC. Connection of transmitter can be seen in figure 19. Electrical connection of transmitter is shown in figure 22 and in electrical scheme in appendix.



Figure 19. Temperature transmitter [43]

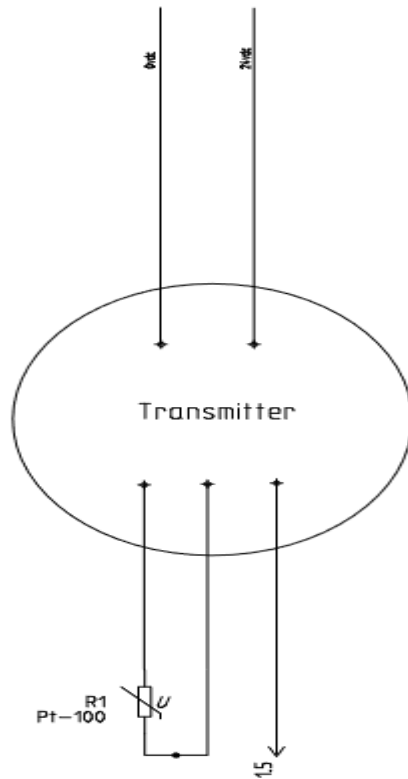


Figure 20. Temperature sensor wiring

Solid state relay

The relay will help to connect heating element to LC so that control signal can be sent to heating element. This relay's coil operate at 3-32 V DC. It can be used to wire heating element to PLC. This relay has a heat sink. This relay is addressed as K₂ in figure 22 and in electrical scheme in appendix.



Figure 21. Solid state relay [44]

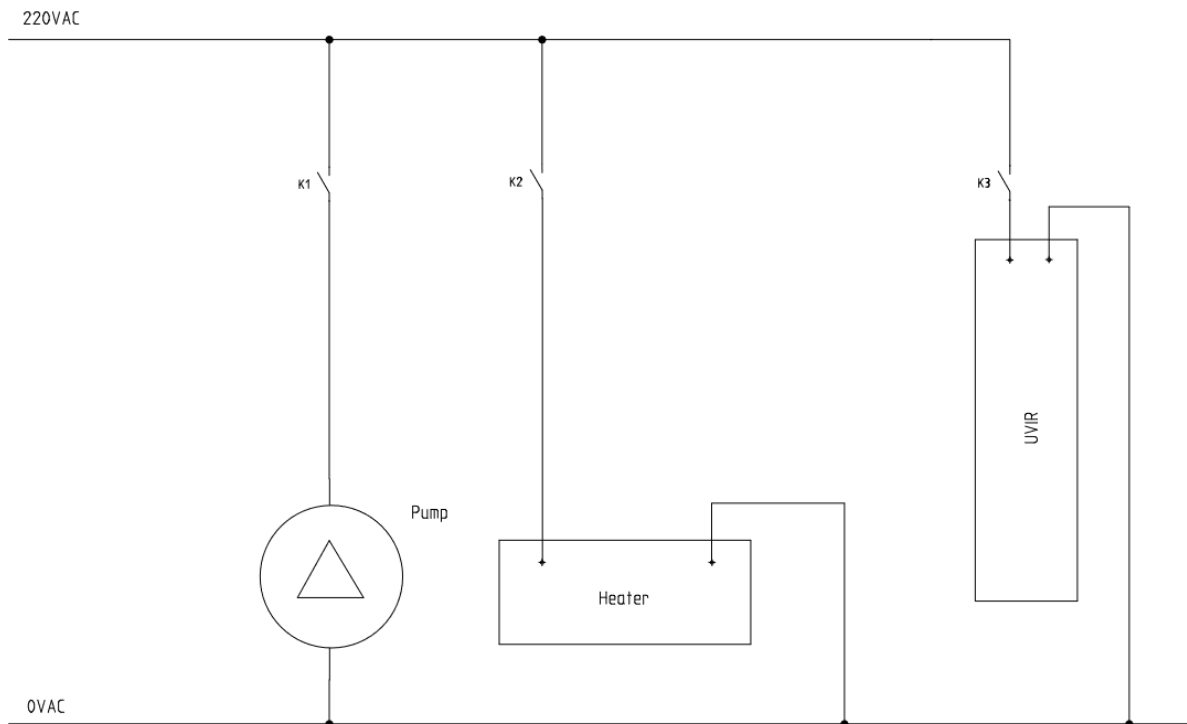


Figure 22. Electrical scheme of pump, heater and UVIR

Flow Meter

A flow meter has been installed for the measurement of flow rate of water. This operated on 24 VDC. The range of flow rate it can measure is 1-30 l/min. Appendix 5 can be referred for datasheet.

Temperature range of this product is -25-80°C. [45] It can be seen in figure 15 how flow meter is connected in system.

Level Sensor

Level sensor has been used to measure the level of water in the tank. Input power supply of this sensor is 24 V DC. The output is 0-10 V signal which has been given to LOGO0BA8. Measurement range of this level sensor is 0-1 m. [46] In figure 15 it can be seen how it is connected in system

7. SOFTWARE DEVELOPMENT

The user should be able to enable machine by a toggle switch. When the tank gets full user can see on display, that system is ready. The user should be able to start showering by pressing the start button. The user can choose between two modes fresh water mode and recycle mode. The user may choose fresh water mode to take a shower with fresh water. Or the user can choose recycling mode and set a number of cycles.

If the user chooses to take a shower with fresh water pump start pumping water from the tank, in 4-way valve just above the pump water passes through the filter and then passes through UVIR. Water comes into shower head, and the user starts taking a shower. The Freshwater mode will be like a normal shower.

If the user chooses recycling mode, the tank should fill, then the user will see a message on display that "system is ready". The user can press start button upon seeing this message. The path for water in three-way valve above pump and UVIR will open, and water goes to the shower head. The user may start taking a shower, used water goes back to the tank and is pumped back through filter and UVIR. When user press stops button, water should be drained out of the tank and system.

A typical end user can use the shower but will not be able to understand what is going on in the background. Target user of this work are people with technical knowledge, should know basic functioning of LOGO 0BA8, simulation and LOGO softcomfort v8. The end user of Showerloop is advised to refer to manual before using the shower. Siemens Logo logic module supports two programming languages Functional Block Diagram and ladder logic. The author decided to write a program in ladder logic because of her familiarity with it.

7.1 Algorithms

Development of software application was started with the development of algorithm. Work was divided into smaller tasks. In next pages, some tasks are described with the help of flow charts.

Recycling mode

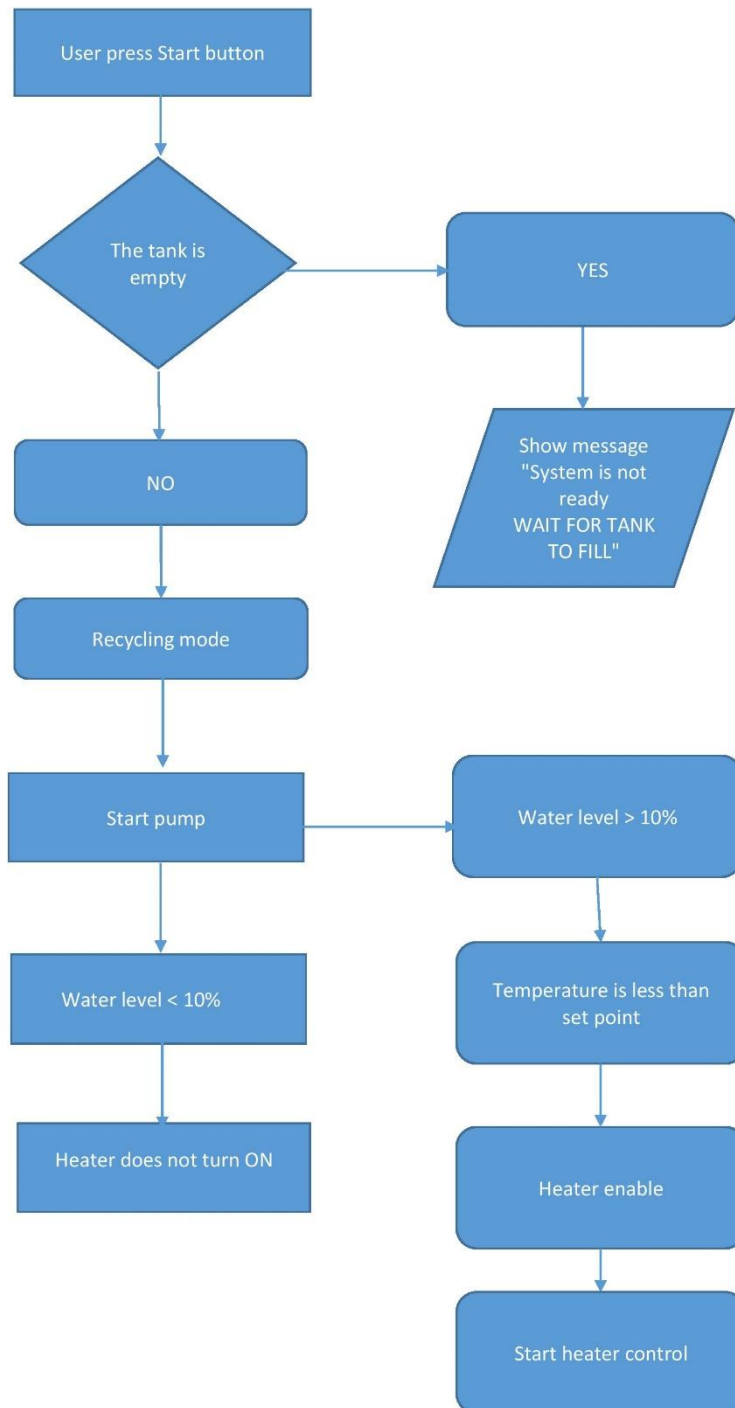


Figure 23. Flow chart Recycling

Draining

The next task was to drain water out of the system. To drain water out below algorithm has been followed.

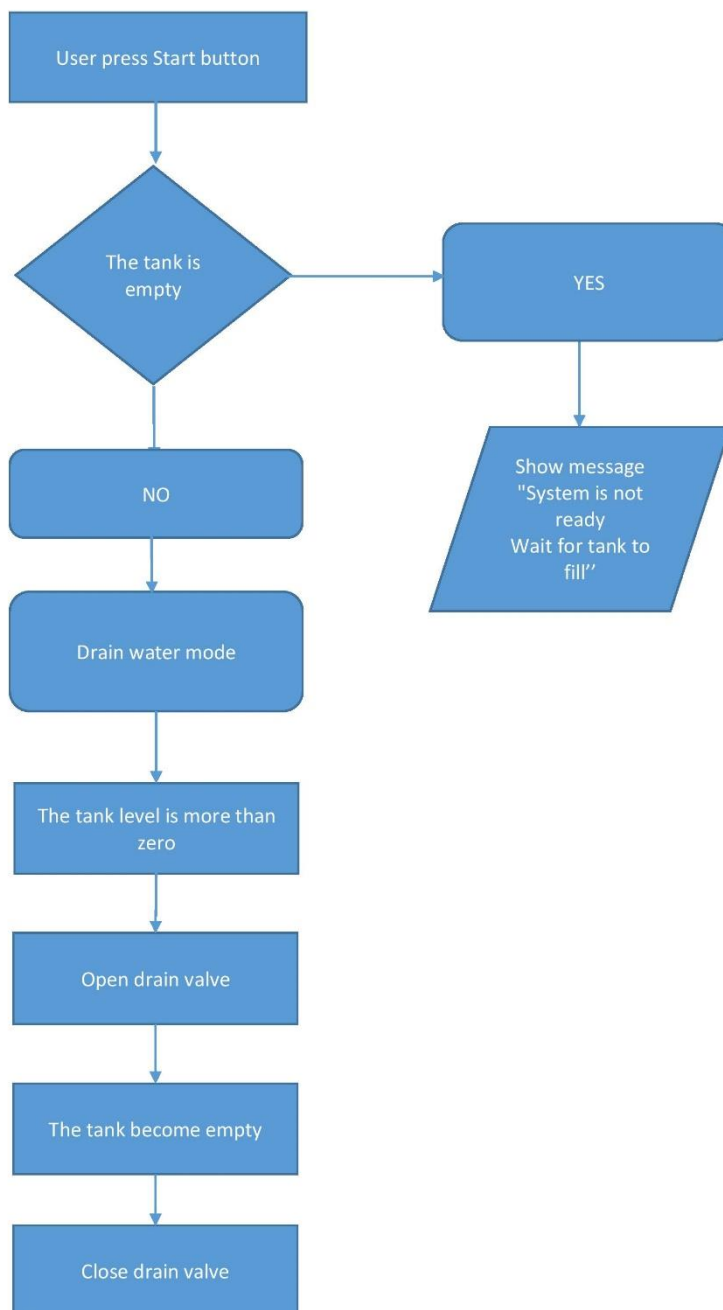


Figure 24. Flow chart draining

Backwash

Showerloop has a backwash facility to clean filters. Backwash is achieved by flowing water in reverse direction. The direction of backwash was decided by Showerloop.org, not the author. To perform backwash pump should be pumping water which enters through UVIR in the system and flows through the filter, first through granular activated carbon then sand filter. Water coming out of backwash should be drained out. Algorithm used to achieve backwash is shown below.

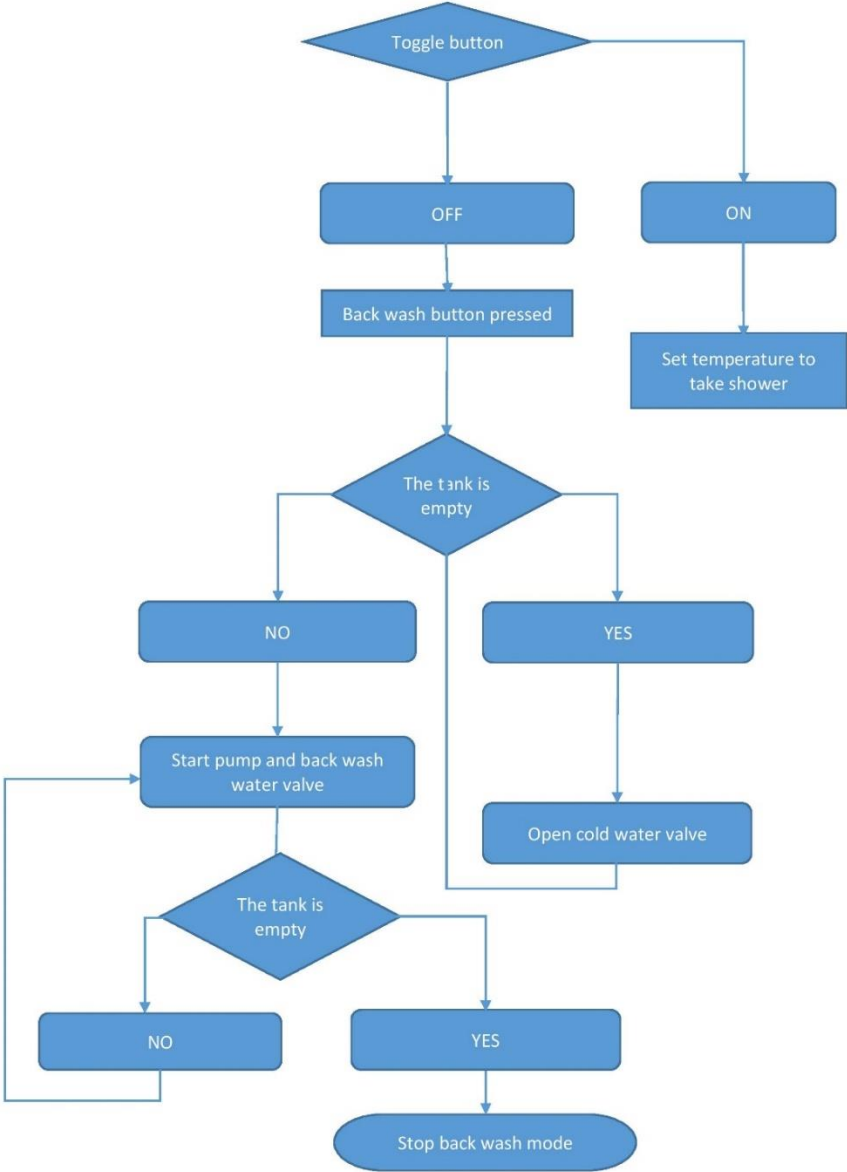


Figure25. Flowchart backwash

Freshwater mode

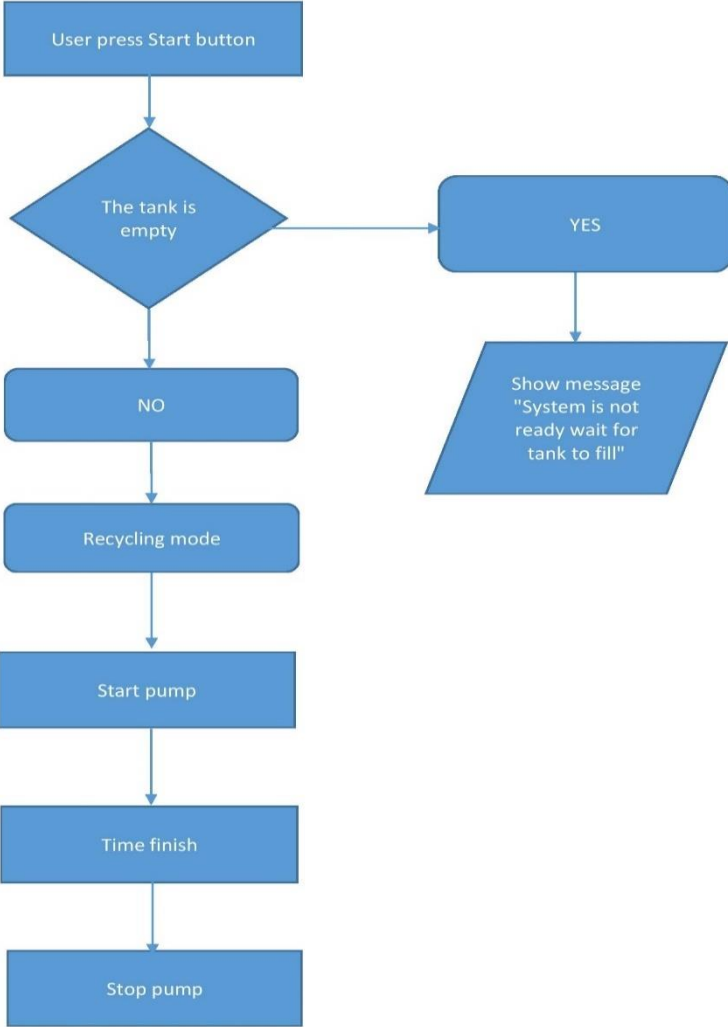


Figure 26. Flowchart freshwater mode

Flow of water

Water comes into the tank by two valves, hot water valve and cold water valve. This water goes to the tank and mixes there. This water is used for showering. Other recyclable showers available in market advise users to attend to their cleaning needs, use soap and shampoo and then start recycling mode. Showerloop has research going on the topic and trying to work out a soap and shampoo pair which can be used in recycling mode. Probably it will also require some changes in filters and system as well. Current suggestion of Showerloop.org is that user should attend to cleaning needs first, use soap or shampoo and then start to recycle mode. At present, it is still a question of research that after how many cycles water becomes unsafe to use, and in software, it has to be left to user to choose time of shower in recycling mode, means the user may set time and take a shower and do not know how many number of cycles have already passed.

7.2 User interface

The designing user-friendly interface is an art in itself. In this work, the aim was not to give this system to end user who buys the product and takes a shower rather it was for system modelling via PLC. Keeping users in mind the interface is interactive but asks for little more information which end user may not be willing to give during taking a shower. In this work possibility to interact with the system have been provided through LOGO 0BA8 display and keys provided on display. The user can make selections through different screens. Alarms and messages are also flashed on the LOGO screen. The user has the possibility to select different modes through screens on LOGO 0BA8 display.

For example selecting recycle mode,



Figure 27. Recycle mode window

It is possible to see the current status of the system. If the user wishes to set temperature of the shower, it is possible to set the desired temperature change "Set temp:" value to which suits you. The user can choose a time for the shower in recycle mode. On this screen, the user has the option to ON or OFF recycle mode.

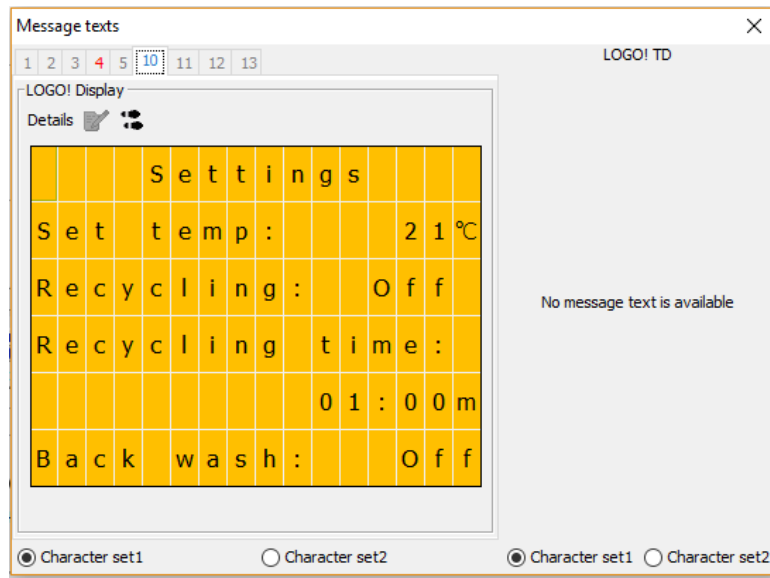


Figure 28. Select temperature window



Figure 29. Settings Screen

On information screen user may see system information about the water level in tank, temperature of water, backwash and pump.

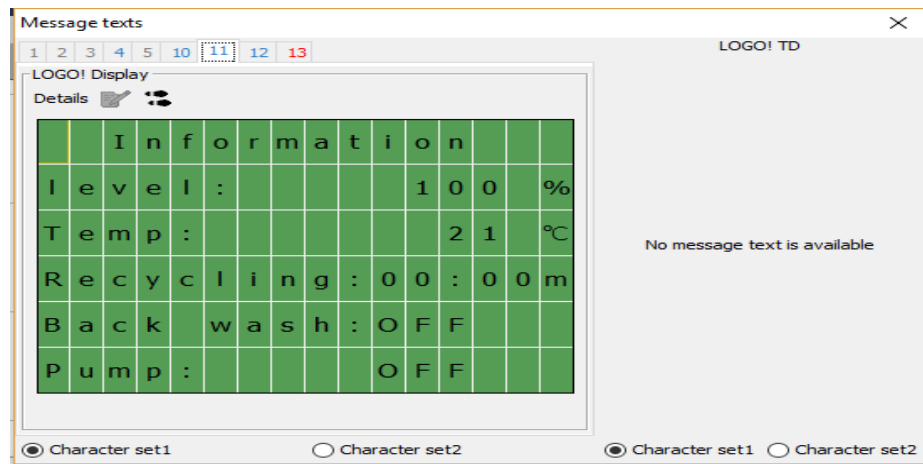


Figure 30. Information window

Message screen shows the message for the user. In figure 31, the user is being asked to press the start button.



Figure 31. Message for user

Different alarm screens show alarms for the user. In the below figure user is being warned to check filter or flow meter. This message will be visible if there is no water flow detected.

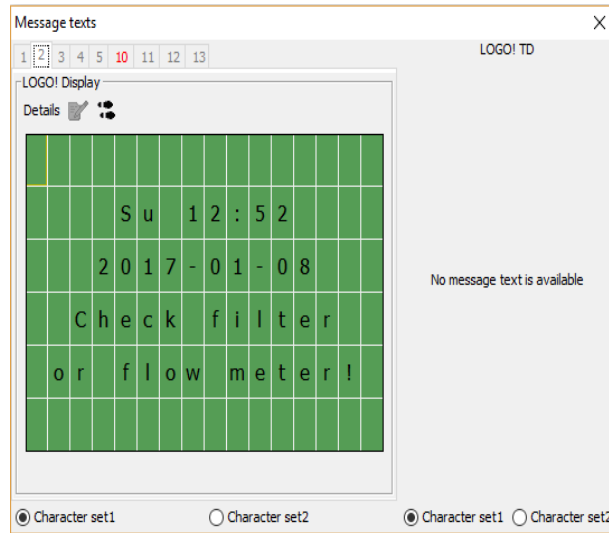


Figure 32. Alarm no signal

In figure 33 the user is being warned to change UVIR lamp as lamps life has ended.

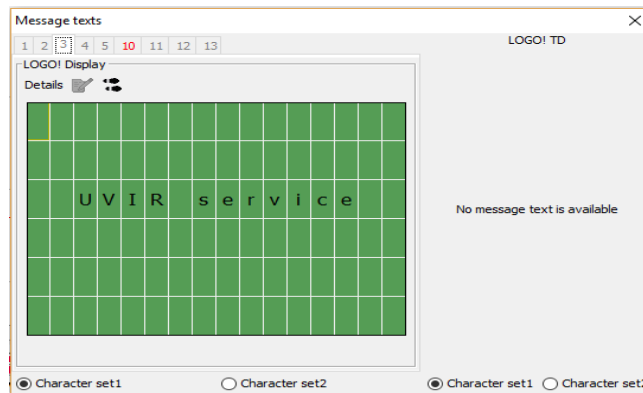


Figure 33. UVIR service

8. TEST AND TEST RESULTS

The program was tested and simulated in Tallinn University of Technology laboratory.

8.1 Test conditions

Test of software was done with hardware monitoring up to some extent as full hardware was not available only switches and input for sensors were available. Test of software was done mainly on simulation. Simulation was used as a proof of concept in absence of full hardware. Actual hardware is expected to perform same as shown in simulation. Inputs from sensors were simulated by variable resistors. The range of resistor was 0-10 K Ohm. Signal of temperature sensor also level sensor were simulated with the use of a variable resistor. Outputs were checked in simulation mode. A toggle button, a green start button and a red stop buttons were wired to LOGO0BA8. Input for an emergency was checked by giving 24 VDC input on the input port.

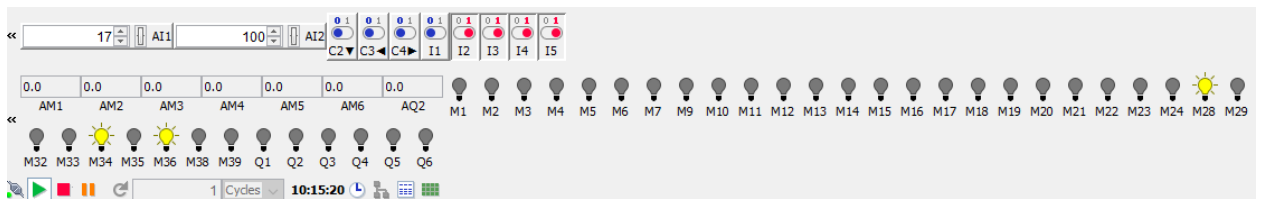


Figure 34. Simulation in LOGO Softcomfort

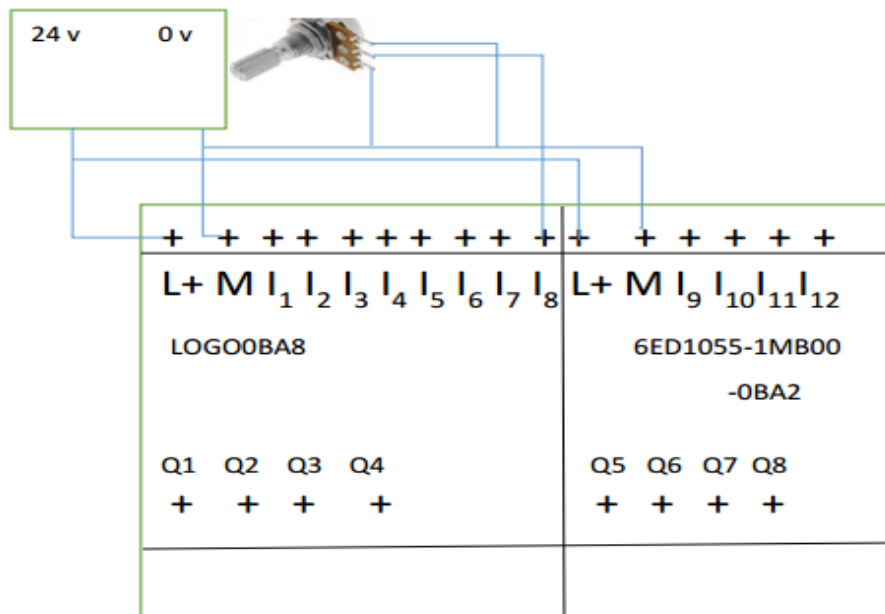


Figure 35. 0-10 V signal simulation by variable resistor

8.2 Test results

Freshwater mode

When fresh water mode is on, the pump is running, output Q₂ is not energised means a path for water in the three-way valve and four-way valve is open, and water is draining out of the system. System acted as expected.

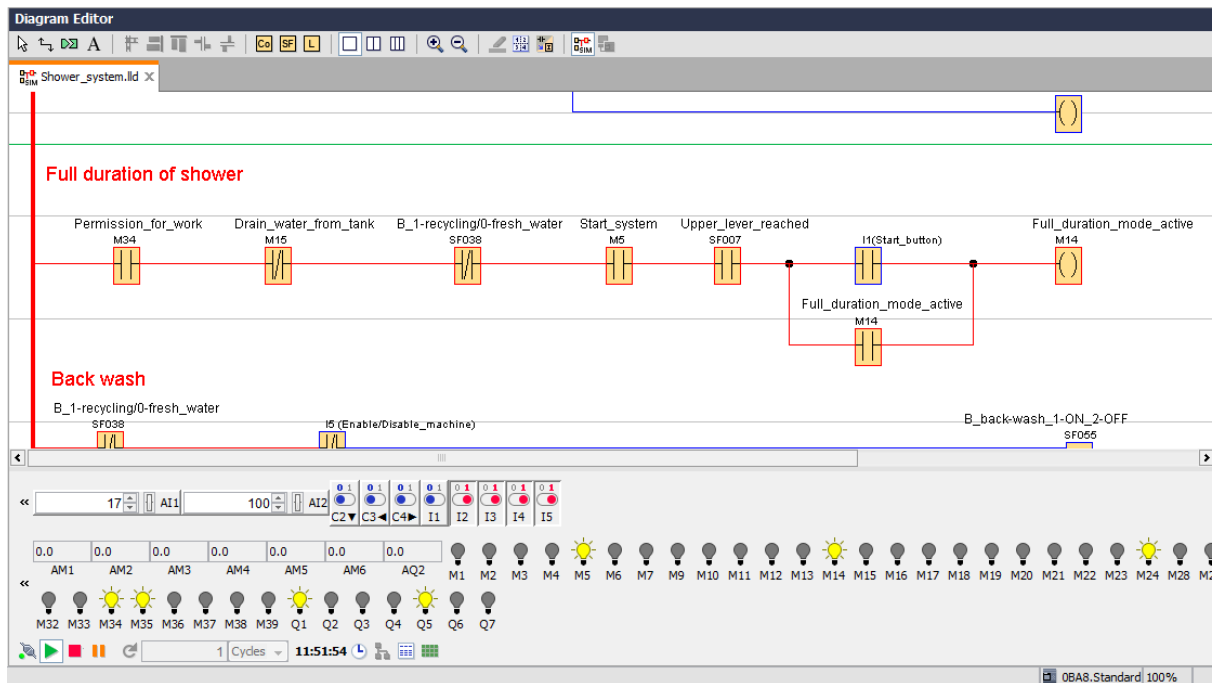


Figure 36. Simulation fresh water mode

Recycling mode

In recycling mode pump is on, the path for water to reach shower head is open, water is not draining out of the system. The system worked as per expectation.

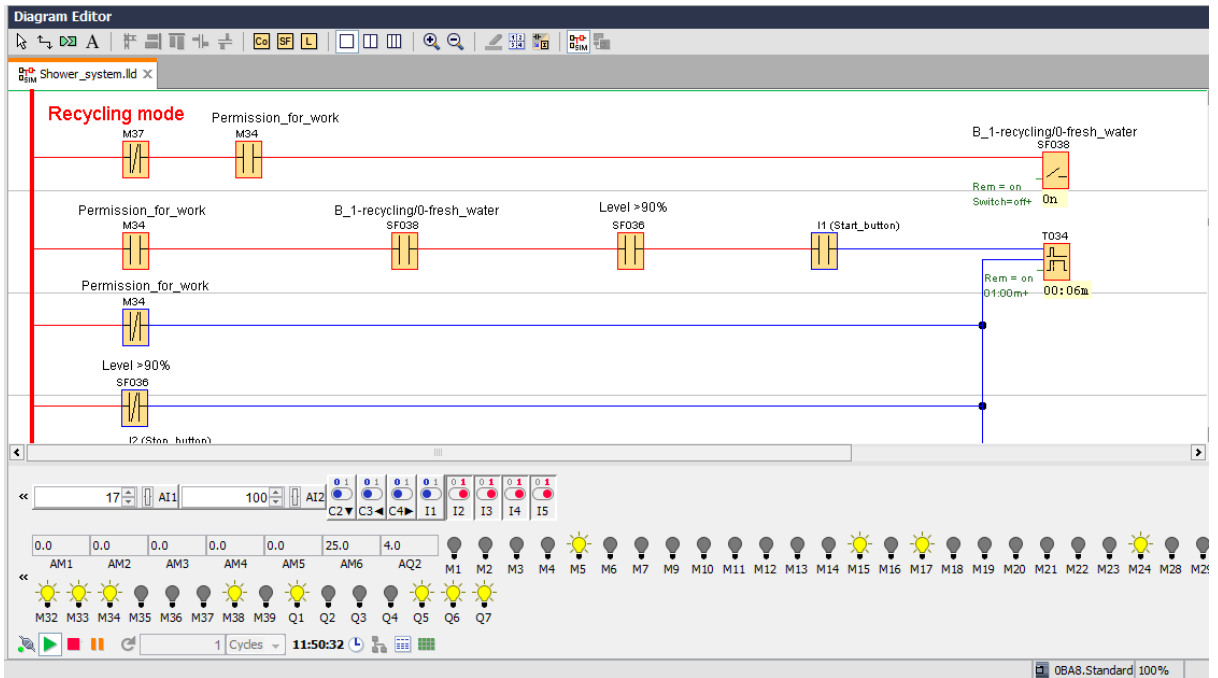


Figure 37. Simulation recycle mode

Drain

Water is draining out of the tank, and hot water and cold water both valves are closed.

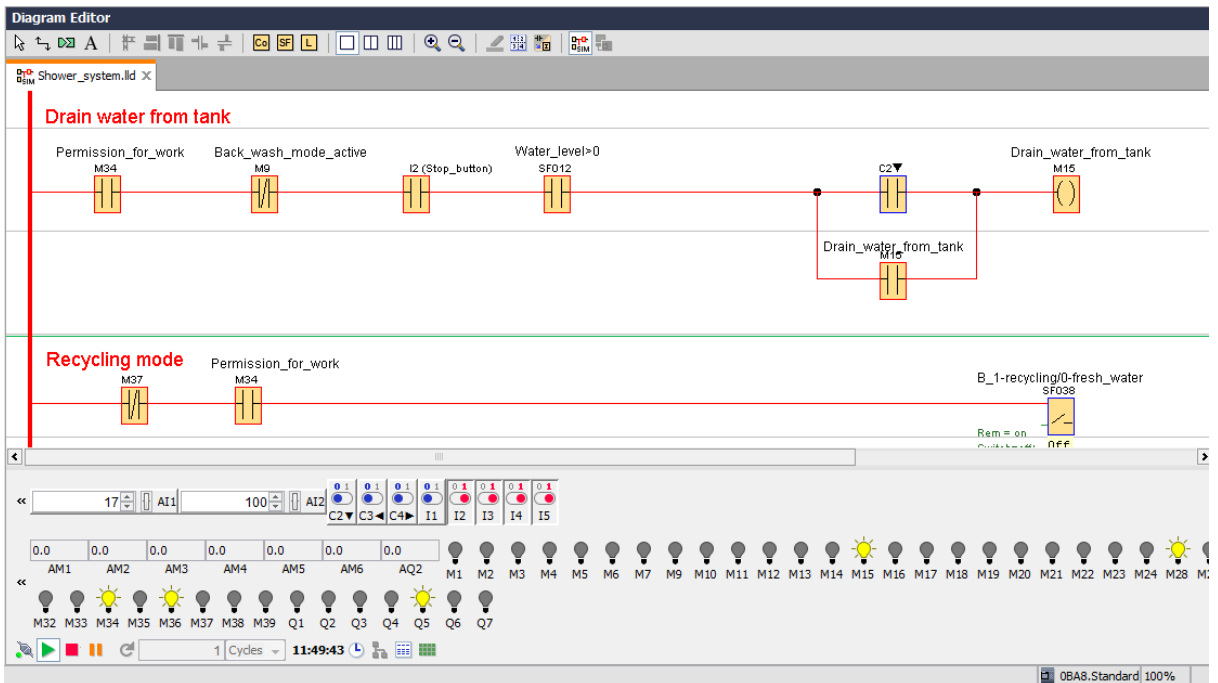


Figure 38. Simulation drain

Backwash

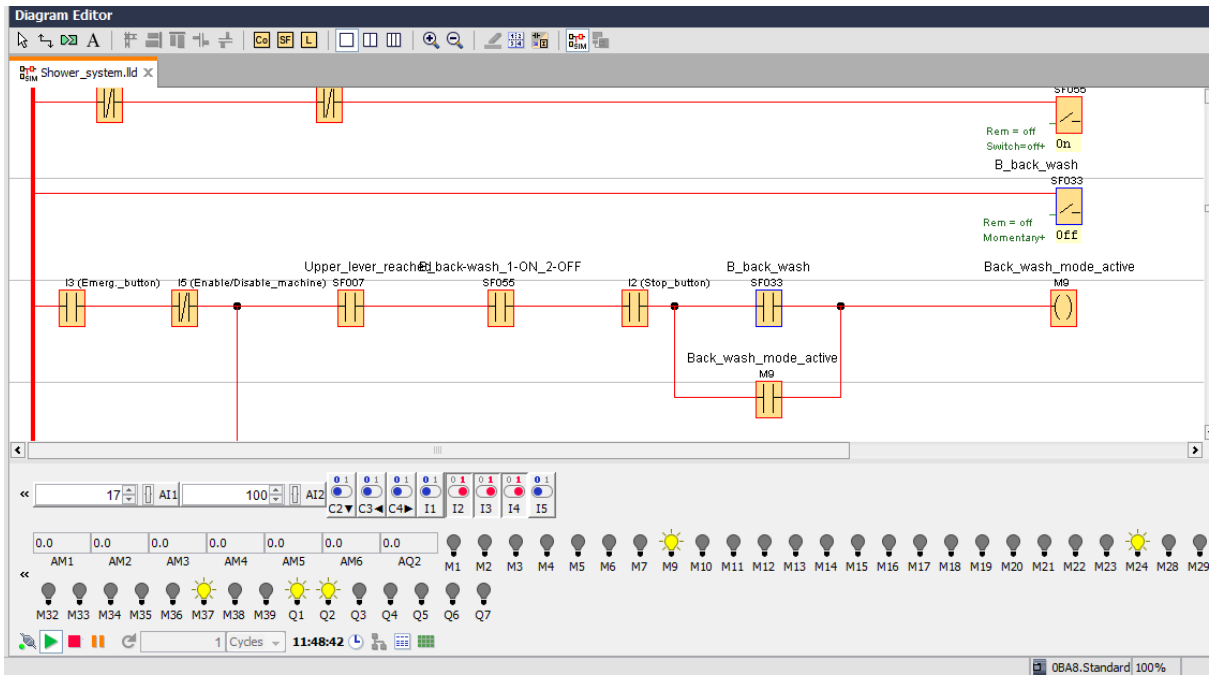


Figure 39. Simulation backwash

Backwash is an important function of Showerloop. It can be seen pump is on, the path for water in the three-way valve and four-way valves is open, and path in another three-way valve for drain/backwash is open for backwash. System acted as required.

9. CONCLUSION AND FUTURE WORK

The objective of designing a control system for Showerloop has been achieved in this thesis work. Components and technologies have been studied to complete the task. Alternate components were proposed when required. A suitable controller was found, and software was developed for controlling the system.

Data collection from sensors can be helpful for users in monitoring their showering behaviour. This collected data can be analysed further which may help in designing user specific modes. Collection and processing of this data will be helpful in measuring water and energy saving for the user. It is possible to add features to communicate with LOGO0BA8 via smartphone, in future this feature can be added for better user experience.

The work was done in Tallinn University of Technology laboratory. Work has not been tested on actual Showerloop. Testing and verifying the system with full hardware remains the next logical step. With the suggestion to use three-way and four-way valves for enabling backwash, more piping and plumbing components will be needed when implementing backwash mechanically. The author has not investigated mechanical components in detail to implement backwash in Showerloop. Piping and instrumentation diagrams need to be made in future work and remain the responsibility of Showerloop.org. As Showerloop is an open source open hardware product it is worth mentioning here that in this work PLC has been used, a different controller from Arduino, other mechanical components and sensors and other tutorials on Showerloop.org need to be reconsidered by a user of open platform community if they wish to implement information from this work.

Human testing of the system also will be very helpful in collecting user feedback about user experience. This feedback can be used to make improvement in human-machine interface. It will be probably a long running project which should have a suitable sample size. Current software remains very cumbersome to use for the end user having a shower, End user is required to refer user manual for using the system in this work. It is because of limitations of hardware used in this work. Next step is to make it more user-friendly. Any design and user interface is considered good when user need not refer to manuals, and it becomes obvious for the user how to use the system. Selecting values is difficult for user as it takes a long time compared to taps in a normal shower. Showerloop prototype does not have backwash implemented on the system. This work is a step forward in the direction of implementing backwash in Showerloop.

In this work, the author has not considered protection of PLC because of touch of wet fingers of the user. Protection from water and humidity need to be taken into consideration. Use of IP67 protection casing and a mechanism to protect HMI need to find and implemented.

This work used Siemens LOGO 0BA8 display for the user interface. A separate HMI can be added in future for better user interaction. In this work LOGO 0BA8 screen and keys have been used for the user interface which remains a little hectic for the end user.

The user has been given the option to use the shower in normal mode only with the limited amount of water that is one tank full of water; the program can be changed to give the option to the user to shower without recycling indefinitely.

As author's task was limited to provide a conceptual solution, Showerloop.org may test the system with suggested and available components and then Showerloop.org may set parameters for final product.

10. Summary

Recyclable Showers are a shower of the future, with exploding population of humans resulting in ever decreasing water bed. Water recycling shower will not only be helpful in saving water and be of use in water scares areas, but they will also be helpful in energy saving resulting in smaller bills if water is not a big problem in some areas. The author believes this work is a step towards a product which helps us reduce our carbon footprints.

This work concludes by making a control system for Showerloop. Showerloop is a shower that recycles water. Water that is used by the user to take a shower is collected in a tank and pumped to filters which cleanse this water. After filtering, this water reaches to UVIR, and it gets disinfected. Microorganisms in water are killed by UV-C radiation. After disinfection, this water reaches to shower head and user take a shower with the same water again. Recycling of water continues till user wants in this model. It is not yet been established after how many cycles water should be discarded. After finishing the shower, the user can discard water so that next user receives fresh water and same water is not shared among users.

The programmable logic controller has been used to control the Showerloop. Sensors, valves and other components have also been suggested in work. Verification of suggested control has been done via simulation and testing on PLC. Testing has not been done on actual hardware, and it remains the future work.

Work is divided into mainly three parts. First knowing and understanding control objective and similar works. Second suggesting new components according to requirement. Third making a control system for Showerloop.

Siemens LOGO0BA8 PLC has been used as a controller in this work, and LOGO softcomfort V8 software was used for programming.

11. KOKKUVÕTE

Vett taaskasutavad dušid on kiirelt kasvava rahvastiku arvu tõttu väheneva puhta vee seisukohalt oluline temaatika. Lisaks vee kokkuhoiule aitavad vett taaskasutavad dušid hoida kokku ka energiat. Töö autor usub, et antud lõputöö näol on tegu sammuga, mis aitab vähendada meie ökoloogilist jalajälge.

See töö hõlmab endas Showerloop ringdušši juhtimissüsteemi loomist. Showerloop on dušš, mis taaskasutab vett. Dušši all kulutatud vesi juhitakse läbi filtrite ja suunatakse kogumismahutisse. Vesi desinfitseeritakse kasutades UVIR seadet. Vees olevad mikroorganismid hävitatakse UV-C kiirguse abil. Desinfitseeritud vesi juhitakse duššipeasse ja kasutaja saab sama vett taaskasutada. Vee taaskasutamine jätkub, kuni kasutaja seda soovib. Töö käigus ei ole välja selgitatud mitu tsükli võib sama vett kasutada. Pärast Showerloopi kasutamise lõpetamist saab kasutaja vee suunata äravoolu. Seeläbi saab tagada, et iga kasutuskord algab uue veega ja kasutajad ei pea jagama juba taaskasutatud vett.

Ringdušši juhtimiseks on kasutatud programmeeritavat loogikakontrollerit. Töös on välja pakutud ka sobivad andurid, ventiilid ja muud komponendid. Töös välja pakutud lahendused on simuleeritud ja testitud, kasutades programmeeritavat loogikakontrollerit. Reaalsel riistvaral ei ole katsetusi tehtud ja see on antud lõputööle loogiline jätk.

Töö on jagatud kolme osasse. Esiteks uurida juhitava seadme olemust ning tutvuda juba olemasolevate lahendustega. Teiseks välja pakkuda seatud eesmärkide täitmiseks sobivad komponendid. Kolmandaks luua ringduššile juhtimissüsteem.

Töös on kasutatud Siemens LOGO0BA8 kontrollerit ja LOGO softcomfort V8 tarkvara.

REFERENCES

1. Showerloop Website Homepage[WWW]
<http://showerloop.org>, [10-10-2016]
2. Thesis Jason Selvarajan and Keiran Holland [WWW]
<https://www.theseus.fi/handle/10024/76148>, [11-10-2016]
3. Thesis Eduard Kobak [WWW]
<https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22156/Kobak.pdf?sequence=3>,
[20-10-2016]
4. Showerloop Website Research page [WWW]
<https://showerloop.org/resources>, [30-10-2016]
5. Quench Showers FAQ [WWW]
<http://quenchshowers.com/faqs/>, [15-11-2016]
6. Quench Showers Home Page [WWW]
<http://quenchshowers.com/>, [16-11-2016]
7. Cintep Shower Introduction [WWW]
<http://www.recyclingshower.com.au/about-cintep/the-company/#.WHSrAWh97IU>,
[20-11-2016]
8. Cintep Shower Homepage [WWW]
<http://www.recyclingshower.com.au/>, [21-11-2016]
9. Orbital Shower FAQ [WWW]
<https://orbital-systems.com/en-eu/faq/>, [22-11-2016]
10. Orbital Shower Homepage [WWW]
<https://orbital-systems.com>, [22-11-2016]
11. Showerloop DIY Instructions [WWW]
<https://showerloop.org/build-it-yourself/>, [16-10-2016]

12. Purion UVIR Datasheet [WWW]
http://www.liwiwa.com/downloadable/download/sample/sample_id/123/, [12-11-2016]
13. Heating tube Merchant's Page
<http://www.bqlzr.com/electrical-element-booster-stainless-steel-heating-tube-for-water-heater-2000w.html>, [11-11-2016]
14. Ink-bird's Product Information Page [WWW]
<http://www.ink-bird.com/products-temperature-controller-itc308.html>, [13-11-2016]
15. Merriam-Webster Meaning [WWW]
<https://www.merriam-webster.com/dictionary/directive>, [06-08-2016]
16. European Commission Drinking Water information [WWW]
http://ec.europa.eu/environment/water/water-drink/legislation_en.html, [12-08-2016]
17. European Union Drinking Water Directive
<http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31998L0083&rid=>
[12-08-2016]
18. IWA Journal [WWW]
<http://wst.iwaponline.com/content/24/9/81>, [20-10-2016]
19. WHO Guidelines For Drinking Water Quality [WWW]
http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf, [22-10-2016]
20. Indian Drinking Water Standard [WWW]
<http://www.cgwb.gov.in/Documents/WQ-standards.pdf> 36, [24-10-2016]
21. Estonian Centre For Standardization Standard Page [WWW]
<https://www.evs.ee/tooted/evs-en-14898-2006+a1-2007>, [28-10-2016]
22. BIS Guide On Human Safety [WWW]
<https://law.resource.org/pub/in/bis/S04/is.11743.1986.pdf>, [29-10-2016]
23. Estonian Centre For Standardization Standard Page [WWW]
<https://www.evs.ee/products/iec-60335-2-105-2016>, [01-11-2016]
24. Estonian Centre For Standardization Standard Page [WWW]

<https://www.evs.ee/products/evs-en-15200-2007>, [03-11-2016]

25. European Commission Manufacturer's Page [WWW]

https://ec.europa.eu/growth/single-market/ce-marking/manufacturers_en, [20-11-2016]

26. Microchip Product Information [WWW]

<http://ww1.microchip.com/downloads/en/DeviceDoc/60001454A.pdf>, [25-11-2016]

27. Curiosity User's Guide [WWW]

<http://ww1.microchip.com/downloads/en/DeviceDoc/40001856A.pdf>, [20-11-2016]

28. Texas Instruments User's Guide [WWW]

<http://www.ti.com/tool/MSP-EXP430FR4133>, [23-11-2016]

29. Texas Instruments Product User's Guide

<http://www.ti.com/lit/ug/slau627a/slau627a.pdf>, [23-11-2016]

30. Texas Instruments Product Information Page [WWW]

<http://www.ti.com/product/MSP430FR6989>, [24-11-2016]

31. Texas Instruments Product Information Page [WWW]

<http://www.ti.com/tool/launchxl-cc2650>, [24-11-2016]

32. ATMEL 2560 Datasheet [WWW]

http://www.atmel.com/Images/Atmel-2549-8-bit-AVR-Microcontroller-ATmega640-1280-1281-2560-2561_datasheet.pdf, [30-11-2016]

33. Microchip Product Information Page [WWW]

<http://www.microchip.com/wwwproducts/en/PIC18F65J50>, [23-11-2016]

34. Microchip Product Information Page [WWW]

<http://www.microchip.com/wwwproducts/en/PIC18F45K22>, [25-11-2016]

35. Siemens LOGO I/O Module Information Page [WWW]

<http://w3.siemens.com/mcms/programmable-logic-controller/en/logic-module-logo/modular-expansion-modules/pages/default.aspx>, [30-11-2016]

36. Siemens I/O Module Datasheet [WWW]

http://www.produktinfo.conrad.com/datenblaetter/1200000-1299999/001268252-da-01-en-LOGO_DM8_12_24R_ERW_MODUL.pdf, [02-12-2016]

37. Siemens Power Module Datasheet [WWW]
<http://www.tme.eu/es/Document/419a38672a0792e8169eb30f453b7620/6EP1332-1SH52.pdf>
[03-12-2016]
38. Siemens LOGO Training Manual [WWW]
https://w3.siemens.com/mcms/sce/de/fortbildungen/ausbildungsunterlagen/zusaetzliche-module/tabcardseiten/Documents/LOGO/sce-logo-manual-0BA8_en.pdf, [02-12-2016]
39. Three-way Relay Merchant's Page [WWW]
<http://roundstar.en.made-in-china.com/productimage/mXeEhgMuYGco-2f1j00sBaTLzrEvjWg/China-Vmi-B-3way-Water-Solenoid-Valve-1-4-.html>, [03-12-2016]
40. Four-way valve Merchant's Page [WWW]
<http://valvesandinstruments.com/solenoid/asco-8344g72-8344g072-24dc-4-way-brass-3-8-in-solenoid-valve-air-water.html>, [17-12-2016]
41. Relpol Relay Merchant's Page [WWW]
<http://www.tme.eu/en/details/pi61p24vdc/electromagnetic-relays-sets/relpol/pi6-1p-24vdc/>,
[18-12-2016]
42. Temperature Sensor Merchant's Page [WWW]
<https://www.amazon.de/dp/B006VA1N0E?psc=1>, [20-12-2016]
43. Temperature Transmitter Merchant's Page [WWW]
https://www.amazon.de/gp/product/B00Q2I7I9K/ref=as_li_qf_sp_asin_il_tl?ie=UTF8&camp=1638&creative=6742&creativeASIN=B00Q2I7I9K&linkCode=as2&tag=great043-21, [21-12-2016]
44. Solid State Relay Merchant's page [WWW]
<http://www.ebay.com/itm/CONTINENTAL-INDUSTRIAL-SOLID-STATE-RELAY-S505-0SJ610-000-3-TO-32-VDC-10A-A-AMP-/252685180128>, [22-12-2016]
45. Flow Sensor Merchant's Page [WWW]
<https://ru.aliexpress.com/item/1-2-1-30L-MIN-Hall-effect-water-liquid-flow-sensor-flow-meter/32614755608.html?spm=2114.41010208.4.196.YD7lrW>, [23-12-2016]
46. Level Sensor Merchant's Page [WWW]
https://www.alibaba.com/product-detail/ESMWLPS-Capacitive-Submersible-level-transmitter_60590276881.html, [23-12-2016]

Appendix 1

Level sensor

Measuring Range	0-1m	Measuring media	Water, oil
Pressure type	Gage pressure	Output signal	0-10 V
Long-term stability	$\pm 0.1\%$ F.S	Temperature drift	$\pm 0.01\%$ FS/ °C
Power Supply	24 V DC (standard)	Accuracy	0.1/ 0.2/0.5
Overload	200% FS	Ambient temperature	-40~85°C
Protection class	IP68	Material	Stainless steel 304
Frequency response	≤ 500 HZ	Media temperature	

Table 7. Level sensor data [45]

Appendix 2

Three-way solenoid valve

Connection form	Thread
Valve structure	Direct acting piston structure
Power supply	AC220 110 V/ DC12 V 24 V
Trademark	Round star
Medium	Liquid/ Gas
Body material	Brass
Temperature range	-5°C- 80°C
Type	Normally open/ Normally closed

Table 8. Three way solenoid valve data [39]

Appendix 3

Four-way solenoid valve



Pilot Operated
Piston/Poppet Solenoid Valves
 Brass Body • 1/4" to 1" NPT

4/2
SERIES
8344

Features

- Sturdy, robust construction
- Piston-operated poppet design provides high flow
- For use with air or water
- Wide range of sizes and flow rates
- Single or dual solenoid constructions
- Dual solenoid can be shifted with a momentary signal and remain in position even if electrical power is lost
- Mountable in any position

Construction

Valve Parts in Contact with Fluids	
Body	Brass
Seals and Disc	NBR
Core Tube	305 Stainless Steel
Core and Plugnut	430F Stainless Steel
Springs	302 Stainless Steel / 17-7PH Stainless Steel
Shading Coil	Copper
Pilot Seat Cartridge and Disc-Holder	CA
Shaft Gasket	PA

Electrical

Standard Coil and Class of Insulation	Watt Rating and Power Consumption				Spare Coil Part Number			
	DC Watts	AC			General Purpose		Explosionproof	
		Watts	VA Holding	VA Inrush	AC	DC	AC	DC
F	10.6	6.1	16	30	238210	238310	238214	238314
F	11.6	10.1	25	50	238610	238710	238614	238714
F	22.6	17.1	40	70	238610	238710	238614	238714

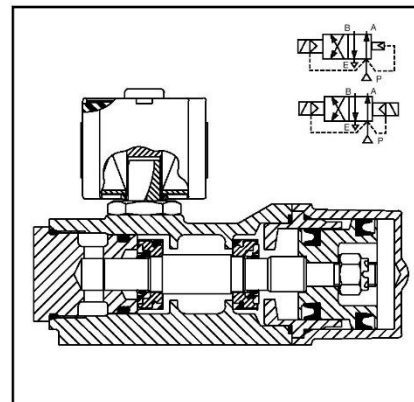
Dual Solenoid Operation: Minimum coil on-time for dual solenoid valves is 0.3 seconds on air service and 1.0 seconds on liquids.
Caution: Do not energize both solenoids simultaneously.
Refer to Engineering Section for details.
Standard Voltages: 24, 120, 240, 480 volts AC, 60 Hz (or 110, 220 volts AC, 50 Hz).
 6, 12, 24, 120, 240 volts DC. Must be specified when ordering.
 Other voltages are available when required.

Solenoid Enclosures

Standard: Watertight, Types 1, 2, 3, 3S, 4, and 4X.
Optional: Explosionproof and Watertight, Types 3, 3S, 4, 4X, 6, 6P, 7, and 9.
 (To order, add prefix "EF" to the catalog number.)
See Optional Features Section for other available options.



4-WAY



Nominal Ambient Temp. Ranges

AC: 32°F to 125°F (0°C to 52°C)
 DC: 32°F to 104°F (0°C to 40°C)

Refer to Engineering Section for details.

Approvals

CSA certified. Meets applicable CE directives.

Important

A Minimum Operating Pressure Differential must be maintained between the pressure and exhaust ports. Supply and exhaust piping must be full area, unrestricted. ASCO flow controls and other similar components must be installed in the cylinder lines only.

- Loss of air pressure may allow valve to shift on dual solenoid constructions.

**4/2
SERIES
8344**



4-WAY

Specifications (English units)

Pipe Size (ins.)	Orifice Size (ins.)	Cv Flow Factor		Operating Pressure Differential (psi)									Max. Fluid Temp. °F		Brass Body		Watt Rating/ Class of Coil Insulation	
				① Min.	Max. AC			Max. DC										
		Press.	Exh.		Air-Inert Gas	Water	Lt. Oil @ 300 SSU	Air-Inert Gas	Water	Lt. Oil @ 300 SSU	AC	DC	Catalog Number	Const. Ref.	AC	DC		
SINGLE SOLENOID																		
1/4	1/4	.80	1.0	10	150	125	125	125	125	125	125	180	150	8344G070	1	10.1/F	11.6/F	
1/4	1/4	.80	1.0	10	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	180	180	8344G000	1	17.1/F	22.6/F	
3/8	3/8	1.4	2.2	10	150	125	125	125	125	125	125	180	150	8344G072	2	10.1/F	11.6/F	
3/8	1/4	.80	1.0	10	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	180	180	8344G001	1	17.1/F	22.6/F	
1/2	3/8	1.4	2.2	10	150	125	125	125	125	125	125	180	150	8344G074	2	10.1/F	11.6/F	
1/2	3/8	1.4	2.2	10	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	180	180	8344G027	2	17.1/F	22.6/F	
3/4	3/4	5.2	5.6	10	150	125	125	125	125	125	125	180	150	8344G076	3	10.1/F	11.6/F	
3/4	3/4	5.2	5.6	10	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	180	180	8344G029	3	17.1/F	22.6/F	
1	3/4	5.2	5.6	10	150	125	125	125	125	125	125	180	150	8344G078	3	10.1/F	11.6/F	
1	3/4	5.2	5.6	10	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	250 ②	180	180	8344G031	3	17.1/F	22.6/F	
DUAL SOLENOID ③																		
1/4	1/4	.80	1.0	10	250	200	125	125	125	100	180	120	8344G044	4	6.1/F	10.6/F		
3/8	3/8	1.4	2.2	10	250	200	125	125	125	100	180	120	8344G080	6	6.1/F	10.6/F		
3/8	3/8	1.4	2.2	10	300	300	200	-	-	-	180	-	8344G050	7	10.1/F	-		
1/2	3/8	1.4	2.2	10	250	200	125	125	125	100	180	120	8344G082	6	6.1/F	10.6/F		
3/4	3/4	5.2	5.6	10	300	300	200	125	125	100	180	120	8344G054	8	10.1/F	10.6/F		
1	3/4	5.2	5.6	10	300	300	200	125	125	100	180	120	8344G056	8	10.1/F	10.6/F		

① 25 psi (1.7 bar) minimum on light oil service. ② For best results, do not use valve rated 250 psi (17 bar) on mainline pressure of less than 125 psi (9 bar).
③ On 50 hertz service, the watt rating for the 6.1/F solenoid is 8.1 watts.

Specifications (Metric units)

Pipe Size (ins.)	Orifice Size (mm)	Kv Flow Factor (m ³ /h)		Operating Pressure Differential (bar)									Max. Fluid Temp. °C		Brass Body		Watt Rating/ Class of Coil Insulation	
				① Min.	Max. AC			Max. DC										
		Press.	Exh.		Air-Inert Gas	Water	Lt. Oil @ 300 SSU	Air-Inert Gas	Water	Lt. Oil @ 300 SSU	AC	DC	Catalog Number	Const. Ref.	AC	DC		
SINGLE SOLENOID																		
1/4	6	.69	.86	0.7	10	9	9	9	9	9	82	65	8344G070	1	10.1/F	11.6/F		
1/4	6	.69	.86	0.7	17 ②	17 ②	17 ②	17 ②	17 ②	17 ②	82	82	8344G000	1	17.1/F	22.6/F		
3/8	10	1.2	1.89	0.7	10	9	9	9	9	9	82	65	8344G072	2	10.1/F	11.6/F		
3/8	6	.69	.86	0.7	17 ②	17 ②	17 ②	17 ②	17 ②	17 ②	82	82	8344G001	1	17.1/F	22.6/F		
1/2	10	1.2	1.89	0.7	10	9	9	9	9	9	82	65	8344G074	2	10.1/F	11.6/F		
1/2	10	1.2	1.89	0.7	17 ②	17 ②	17 ②	17 ②	17 ②	17 ②	82	82	8344G027	2	17.1/F	22.6/F		
3/4	19	4.5	4.80	0.7	10	9	9	9	9	9	82	65	8344G076	3	10.1/F	11.6/F		
3/4	19	4.5	4.80	0.7	17 ②	17 ②	17 ②	17 ②	17 ②	17 ②	82	82	8344G029	3	17.1/F	22.6/F		
1	19	4.5	4.80	0.7	10	9	9	9	9	9	82	65	8344G078	3	10.1/F	11.6/F		
1	19	4.5	4.80	0.7	17 ②	17 ②	17 ②	17 ②	17 ②	17 ②	82	82	8344G031	3	17.1/F	22.6/F		
DUAL SOLENOID ③																		
1/4	6	.80	.86	0.7	17	14	9	9	9	7	82	49	8344G044	4	6.1/F	10.6/F		
3/8	10	1.4	1.89	0.7	17	14	9	9	9	7	82	49	8344G080	6	6.1/F	10.6/F		
3/8	10	1.4	1.89	0.7	21	21	14	-	-	-	82	-	8344G050	7	10.1/F	-		
1/2	10	1.4	1.89	0.7	17	14	9	9	9	7	82	49	8344G082	6	6.1/F	10.6/F		
3/4	19	5.2	4.80	0.7	21	21	14	9	9	7	82	49	8344G054	8	10.1/F	10.6/F		
1	19	5.2	4.80	0.7	21	21	14	9	9	7	82	49	8344G056	8	10.1/F	10.6/F		

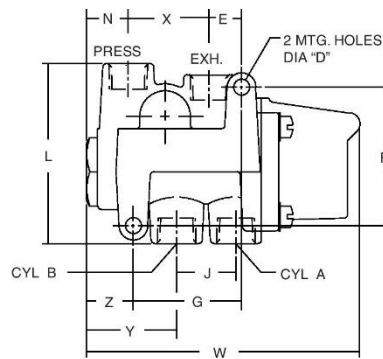
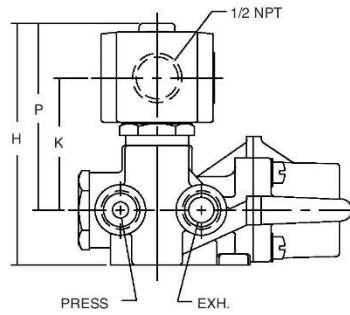
① 25 psi (1.7 bar) minimum on light oil service. ② For best results, do not use valve rated 250 psi (17 bar) on mainline pressure of less than 125 psi (9 bar).
③ On 50 hertz service, the watt rating for the 6.1/F solenoid is 8.1 watts.

Dimensions inches (mm)

Const. Ref.		ØD	E	F	G	H	J	K	L	N	P	W	X	Y	Z	Exhaust Pipe Size
1	ins.	Ø .28	.56	2.41	1.88	4.08	1.03	2.15	3.13	.72	3.12	4.75	1.41	1.56	.81	3/8
	mm	Ø 7.1	14	61	48	104	26	55	80	18	79	121	36	40	21	3/8
2	ins.	Ø .34	.75	3.12	2.63	4.06	1.50	1.97	3.18	.83	2.94	6.06	1.88	1.90	.84	1/2
	mm	Ø 8.6	19	79	67	103	38	50	81	21	75	154	47	48	21	1/2
3	ins.	Ø .34	1.34	3.81	3.88	4.86	2.09	2.34	4.56	1.56	3.31	8.25	2.12	2.63	1.16	1
	mm	Ø 8.6	34	97	99	123	53	59	116	39	84	210	54	67	30	1
4	ins.	Ø .28	.56	2.41	1.88	4.34	1.03	2.52	3.13	.72	3.38	4.81	1.41	1.56	.81	3/8
	mm	Ø 7.1	14	61	48	110	26	64	80	18	86	122	36	40	21	3/8
6	ins.	Ø .34	.75	3.12	2.63	4.50	1.50	2.52	3.18	.83	3.38	6.06	1.88	1.90	.84	1/2
	mm	Ø 8.6	19	79	67	114	38	64	81	21	86	154	47	48	21	1/2
7	ins.	Ø .34	.75	3.12	2.63	4.68	1.50	2.59	3.18	.83	3.56	6.06	1.88	1.90	.84	1/2
	mm	Ø 8.6	19	79	67	119	38	66	81	21	90	154	47	48	21	1/2
8	ins.	Ø .34	1.34	3.81	3.88	5.56	2.09	3.03	4.56	1.55	4.00	8.25	2.12	2.63	1.16	1
	mm	Ø 8.6	34	97	99	141	53	77	116	39	102	210	54	67	30	1

4-WAY

Const. Ref 1 - 3



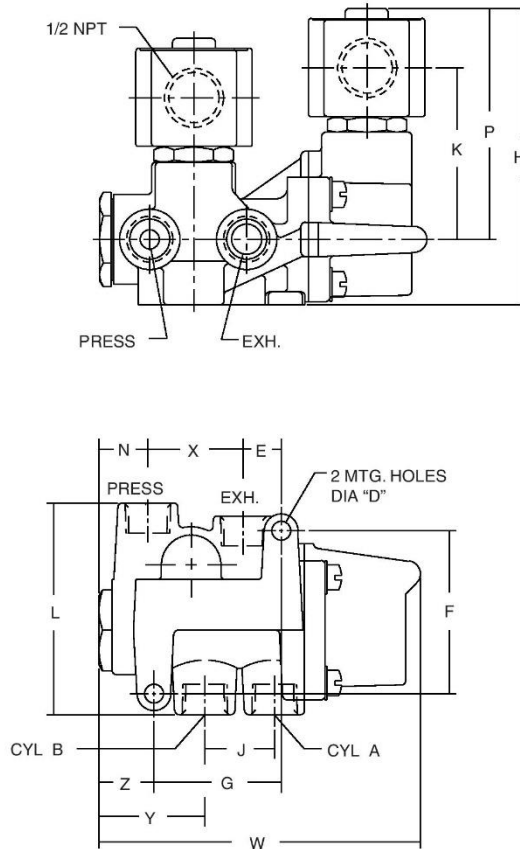
8344R1

85

Dimensions inches (mm)

4-WAY

Const. Ref. 4 - 8



Appendix 5

Flow sensor

Specification [44]

Function: Flow sensor

Flow rate: 1-30L/min

Operating voltage: 24 VDC

Temperature range: -25 °C to 80°C

Accuracy: 5%- 10%9+*

Appendix 6

Input Output module

SIEMENS

Datasheet

6ED1055-1MB00-0BA2



LOGO! DM8 12/24R, EXP. MODULE PU/I/O: 12,
24V/12V/24V/RELAIS, 2TE, 4 DI/4 DO FOR LOGO! 8

Installation type/mounting	
Mounting	on 35 mm DIN rail, 2 spacing units wide
Supply voltage	
12 V DC	Yes
24 V DC	Yes
permissible range, lower limit (DC)	10.8 V
permissible range, upper limit (DC)	28.8 V
Digital inputs	
Number of digital inputs	4
Input voltage	
• Type of input voltage	DC
• for signal "0"	< 5 V DC
Input current	
• for signal "0", max. (permissible quiescent current)	0.88 mA
• for signal "1", typ.	4.2 mA
Input delay (for rated value of input voltage) for standard inputs	
— at "0" to "1", max.	1.5 ms
— at "1" to "0", max.	1.5 ms
Digital outputs	
Number of digital outputs	4; Relays
Short-circuit protection	No
Controlling a digital input	Yes
Switching capacity of the outputs	
• Lamp load, max.	1 000 W
Output current	

• for signal "1" rated value	5 A
Parallel switching of 2 outputs	
• for uprating	No
Switching frequency	
• with resistive load, max.	2 Hz
• with inductive load, max.	0.5 Hz
• mechanical, max.	10 Hz
Relay outputs	
Switching capacity of contacts	
— with inductive load, max.	3 A
— with resistive load, max.	5 A
EMC	
Emission of radio interference acc. to EN 55 011	
• Emission of radio interference acc. to EN 55 011 (limit class B)	Yes
Degree and class of protection	
IP20	Yes
Standards, approvals, certificates	
CSA approval	Yes
UL approval	Yes
FM approval	Yes
developed in accordance with IEC 61131	Yes
Marine approval	
• Marine approval	Yes
Ambient conditions	
Operating temperature	
• min.	0 °C
• max.	55 °C
Dimensions	
Width	35.5 mm
Height	90 mm
Depth	58 mm
last modified:	21.08.2014

Appendix 7

Power module

SIEMENS

Data sheet

6EP1332-1SH52



LOGO!POWER 24 V/4 A
 LOGO!POWER 24 V/4 A STABILIZED POWER SUPPLY INPUT:
 100-240 V AC (110-300 V DC) OUTPUT: 24 V/4 A DC

Input	
Input	1-phase AC or DC
Rated voltage value V_{in} rated	100 ... 240 V
Voltage range AC	85 ... 264 V
Input voltage	
• for DC	110 ... 300 V
Wide-range input	Yes
Oversoltage resistance	$2.3 \times V_{in}$ rated, 1.3 ms
Mains buffering at I_{out} rated, min.	40 ms; at $V_{in} = 187$ V
Rated line frequency	50 ... 60 Hz
Rated line range	47 ... 63 Hz
Input current	
• at rated input voltage 120 V	1.95 A
• at rated input voltage 230 V	0.97 A
Switch-on current limiting (+25 °C), max.	30 A
I^2t , max.	2.5 A ² ·s
Built-in incoming fuse	internal
Protection in the mains power input (IEC 898)	Recommended miniature circuit breaker: from 16 A characteristic B or from 10 A characteristic C
Output	
Output	Controlled, isolated DC voltage
Rated voltage V_{out} DC	24 V
Total tolerance, static \pm	3 %
Static mains compensation, approx.	0.1 %
Static load balancing, approx.	1.5 %

Residual ripple peak-peak, max.	200 mV
Residual ripple peak-peak, typ.	30 mV
Spikes peak-peak, max. (bandwidth: 20 MHz)	300 mV
Spikes peak-peak, typ. (bandwidth: 20 MHz)	60 mV
Adjustment range	22.2 ... 26.4 V
Product function Output voltage adjustable	Yes
Output voltage setting	via potentiometer
Status display	Green LED for output voltage OK
On/off behavior	No overshoot of Vout (soft start)
Startup delay, max.	0.5 s
Voltage rise, typ.	15 ms
Rated current value Iout rated	4 A
Current range	0 ... 4 A
• Note	+55 ... +70 °C: Derating 2%/K
Active power supplied typical	96 W
Parallel switching for enhanced performance	Yes
Numbers of parallel switchable units for enhanced performance	2

Efficiency	
Efficiency at Vout rated, Iout rated, approx.	89 %
Power loss at Vout rated, Iout rated, approx.	12 W
Active power loss during no-load operation maximum	2 W

Closed-loop control	
Dynamic mains compensation (Vin rated ± 15 %), max.	0.2 %
Dynamic load smoothing (Iout: 10/90/10 %), Uout \pm typ.	1.5 %
Load step setting time 10 to 90%, typ.	1 ms
Load step setting time 90 to 10%, typ.	1 ms

Protection and monitoring	
Output overvoltage protection	Yes, according to EN 60950-1
Current limitation, typ.	5.2 A
Property of the output Short-circuit proof	Yes
Short-circuit protection	Constant current characteristic
Enduring short circuit current RMS value	
• maximum	7.9 A
Overload/short-circuit indicator	-

Safety	
Primary/secondary isolation	Yes
Galvanic isolation	Safety extra-low output voltage Uout acc. to EN 60950-1 and EN 50178
Protection class	Class II (without protective conductor)

CE mark	Yes
UL/CSA approval	Yes
UL/cUL (CSA) approval	cULus-listed (UL 508, CSA C22.2 No. 107.1), File E197259; cURus-recognized (UL 60950, CSA C22.2 No. 60950), File E151273
Explosion protection	ATEX (EX) II 3G Ex nA IIC T3; cCSAus (CSA C22.2 No. 213-M1987, ANSI/ISA-12.12.01-2007) Class I, Div. 2, Group ABCD, T4
Certificate of suitability IECEx	No
Certificate of suitability NEC Class 2	No
FM approval	Class I, Div. 2, Group ABCD, T4
CB approval	Yes
Marine approval	GL, ABS, BV, DNV, LRS
Degree of protection (EN 60529)	IP20

EMC	
Emitted interference	EN 55022 Class B
Supply harmonics limitation	EN 61000-3-2
Noise immunity	EN 61000-6-2

Operating data	
Ambient temperature	
<ul style="list-style-type: none"> • during operation — Note • during transport • during storage 	-20 ... +70 °C with natural convection -40 ... +85 °C -40 ... +85 °C
Humidity class according to EN 60721	Climate class 3K3, no condensation

Mechanics	
Connection technology	screw-type terminals
Connections	
<ul style="list-style-type: none"> • Supply input • Output • Auxiliary 	L, N: 1 screw terminal each for 0.5 ... 2.5 mm ² single-core/finely stranded +, -: 2 screw terminals each for 0.5 ... 2.5 mm ² -
Width of the enclosure	90 mm
Height of the enclosure	90 mm
Depth of the enclosure	52.6 mm
Weight, approx.	0.34 kg
Product property of the enclosure housing for side-by-side mounting	Yes
Installation	Snaps onto DIN rail EN 60715 35x7.5/15
Other information	Specifications at rated input voltage and ambient temperature +25 °C (unless otherwise specified)

Appendix 8

LOGO Logic module

SIEMENS

Datasheet

6ED1052-1MD00-0BA8



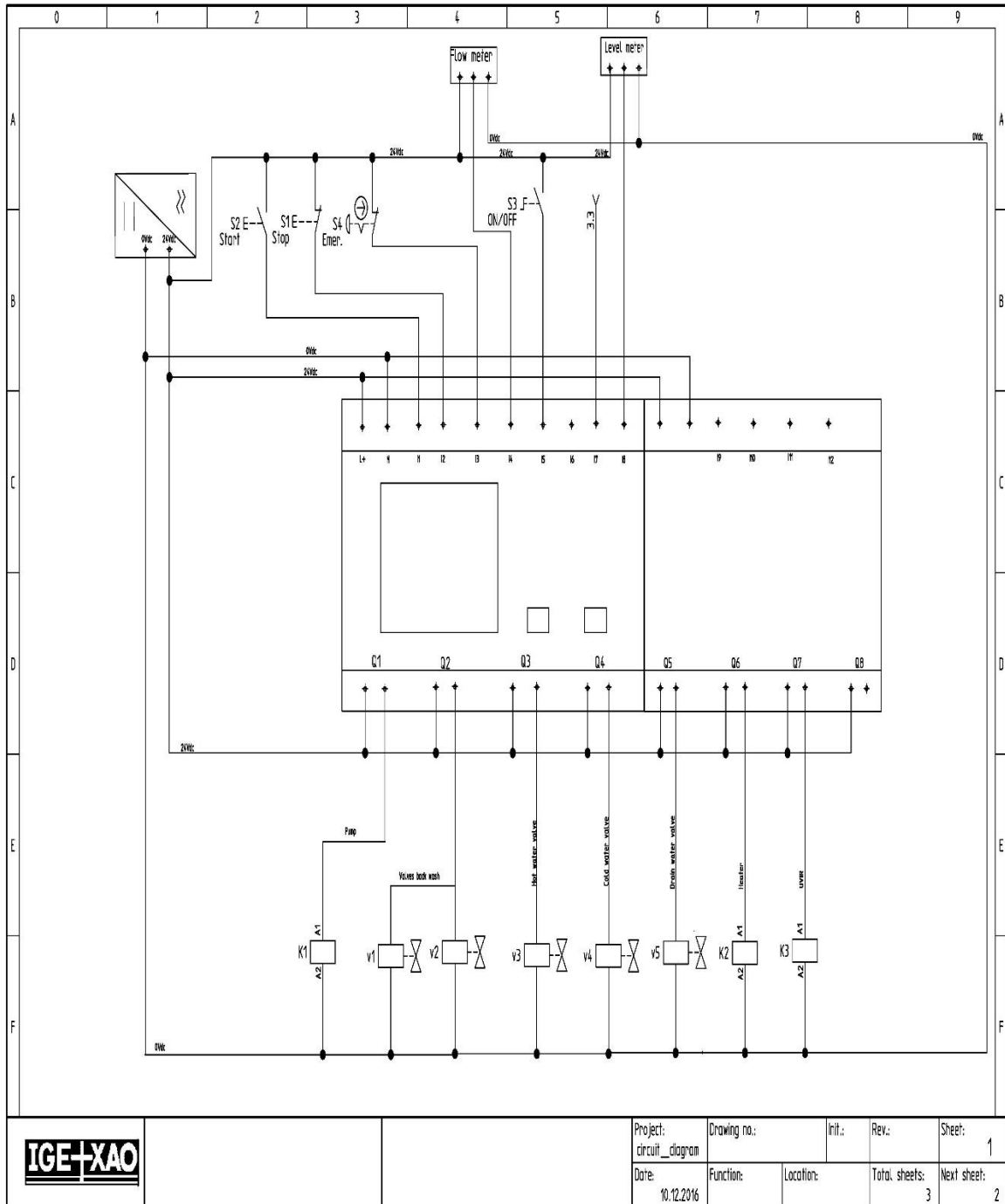
LOGO!12/24RCE, LOGIC MOD., DISPL. PU/I/O: 12/24V DC/RELAY, 8 DI (4A)/4 DO; MEM 400 BLOCKS EXPANDABLE, ETHERNET BUILD IN WEB-SERVER, DATALOG STANDARD MICRO SD CARD FOR LOGO! SOFT COMFORT V8 PREVIOS PROJECT USABEL

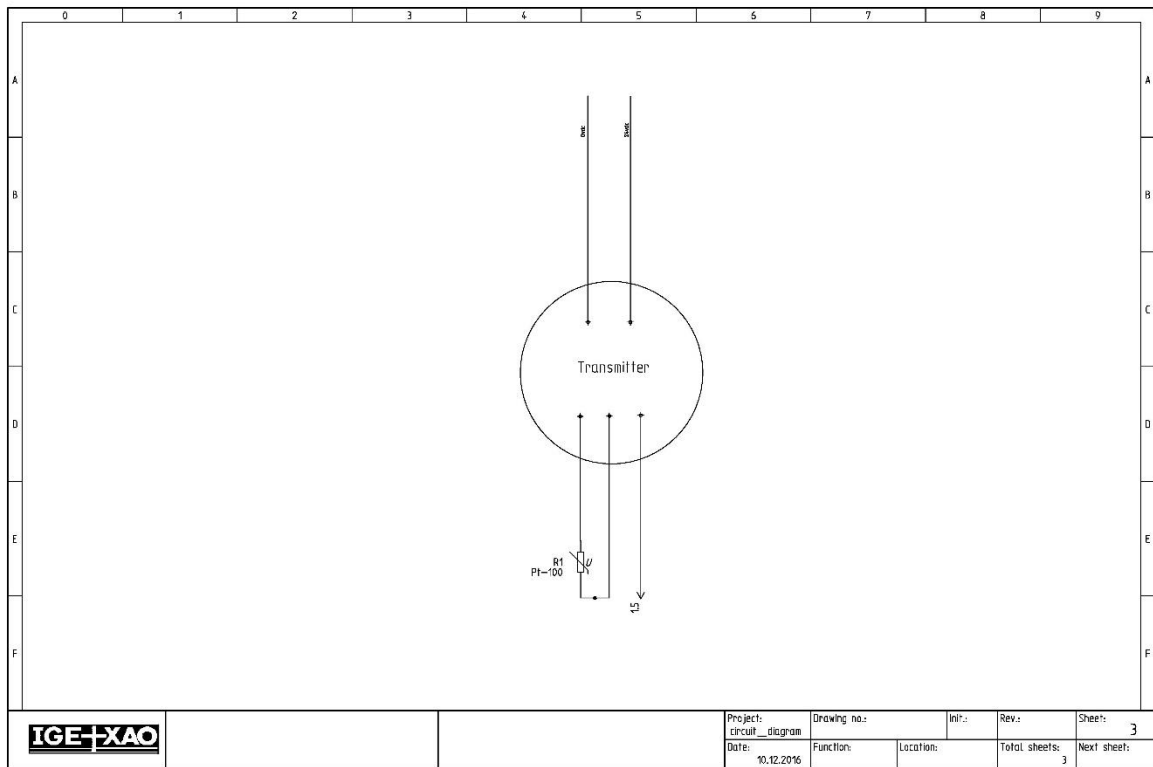
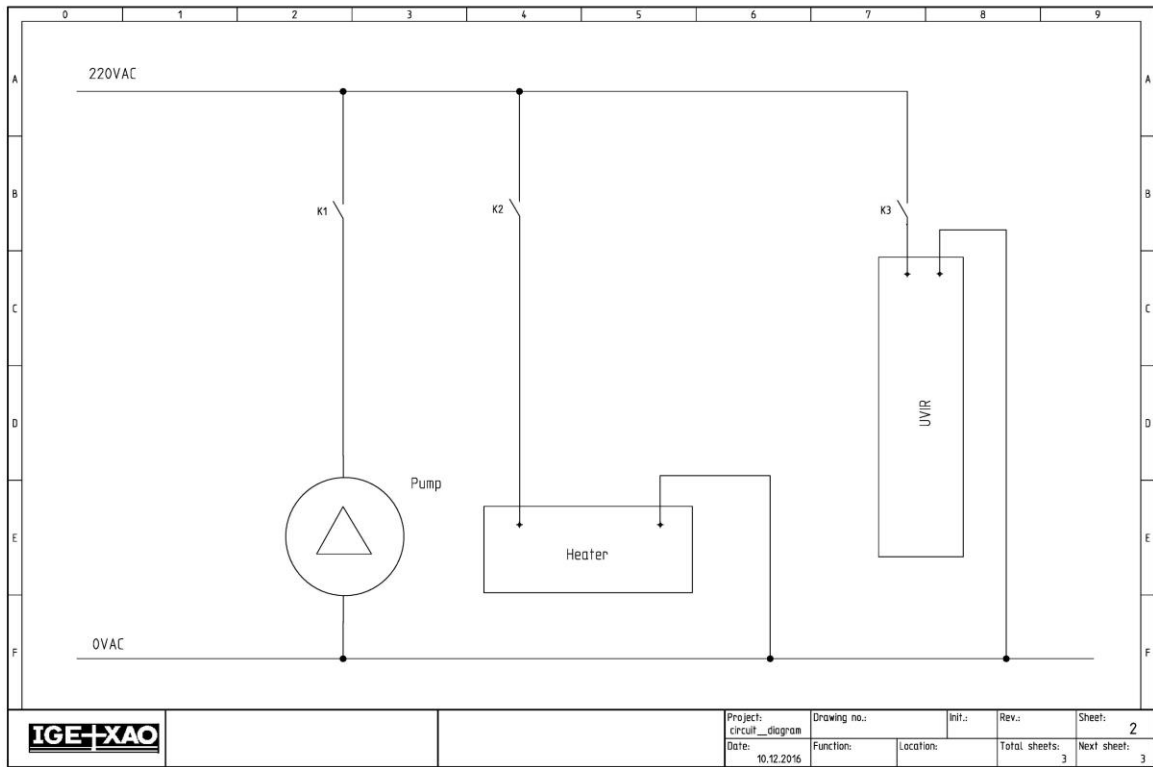
Installation type/mounting	
Mounting	on 35 mm DIN rail, 4 spacing units wide
Supply voltage	
12 V DC	Yes
24 V DC	Yes
permissible range, lower limit (DC)	10.8 V
permissible range, upper limit (DC)	28.8 V
Time of day	
Time switching clocks	
• Number	8
• Power reserve	480 h
Digital inputs	
Number of digital inputs	8; Of which 4 can be used in analog mode (0 to 10 V)
Digital outputs	
Number of digital outputs	4; Relays
Short-circuit protection	No; external fusing necessary
Output current	
• for signal "1" permissible range for 0 to 55 °C, max.	10 A
Relay outputs	
Switching capacity of contacts	
— with inductive load, max.	3 A
— with resistive load, max.	10 A
EMC	
Emission of radio interference acc. to EN 55 011	
• Emission of radio interference acc. to EN 55 011 (limit class B)	Yes

Degree and class of protection	
IP20	Yes
Standards, approvals, certificates	
CSA approval	Yes
UL approval	Yes
FM approval	Yes
developed in accordance with IEC 61131	Yes
acc. to VDE 0631	Yes
Marine approval	
• Marine approval	Yes
Ambient conditions	
Operating temperature	
• min.	0 °C
• max.	55 °C
Dimensions	
Width	71.5 mm
Height	90 mm
Depth	60 mm
last modified:	21.08.2014

Appendix 9

Electrical scheme





Appendix 10

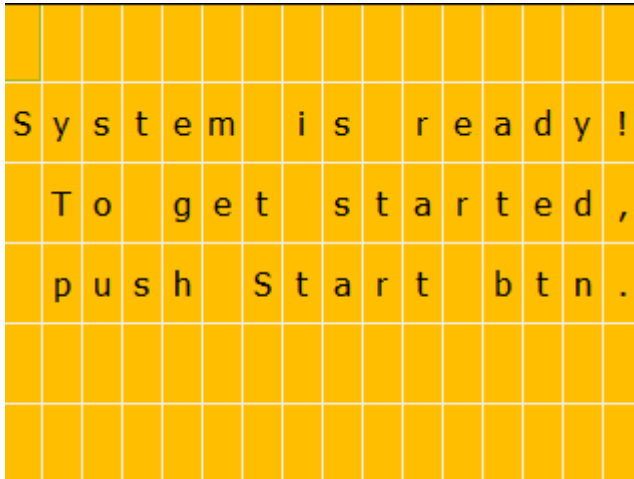
User manual

Using Showerloop in normal mode:

1. Switch ON toggle button

The tank of Showerloop begins to fill with water.

2. When tank gets full user will see this message on the screen,



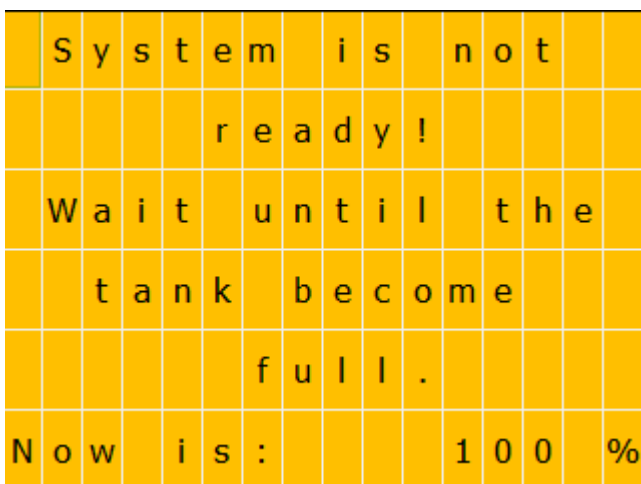
Now Showerloop is ready, press start button.

3. As the user will press start button water will begin to flow from the showerhead, the user can step in and enjoy the shower.

4. To pause shower, press Stop button and water will stop pouring from the showerhead. If the user wants to start it again, the user needs to press Start button.

Note: If user press starts button before tank becomes full user will see below message on display.

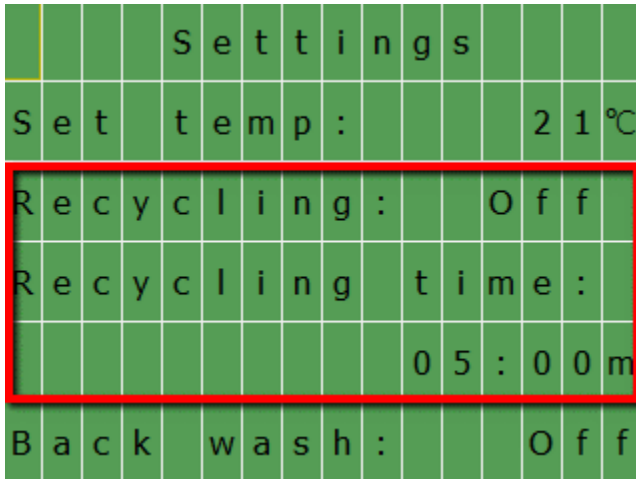
Note: if machine fill the tank you cannot stop this process only when it drain water



Using Showerloop in recycling mode:

1. To activate recycling mode select "Recycling", select status ON.

Now enter desired time by changing "Recycling time" value.



2. Put on the toggle button.

3. When Showerloop is ready to be used the user will see a message on the Logo display that it is ready and the user can press the start button.

4. Press Start button and water will begin to pour from the shower head, step in enjoy the shower.

5. To pause shower, press stop button and shower head will stop pouring water from the showerhead. If the user wants to start it again, the user needs to press the start button.

Note:

Notice: if machine fill the tank you cannot stop this process only when it drain water

Backwash mode:

1. To activate back, wash mode user should turn toggle button OFF and put "Back wash" button to "ON" on LOGO 0BA8 screen.

			S	e	t	t	i	n	g	s					
S	e	t	t	e	m	p	:				2	1	°C		
R	e	c	y	c	l	i	n	g	:		O	f	f		
R	e	c	y	c	l	i	n	g	t	i	m	e	:		
										0	5	:	0	0	m
B	a	c	k	w	a	s	h	:			O	f	f		

If there is water in the tank backwashing will start automatically, if the tank is empty system will fill the tank with cold water and then will start backwashing.

Temperature control:

- 1) The user can select the desired temperature by going to "Set temp" and select the value of his/her choice.

			S	e	t	t	i	n	g	s					
S	e	t	t	e	m	p	:				2	1	°C		
R	e	c	y	c	l	i	n	g	:		O	f	f		
R	e	c	y	c	l	i	n	g	t	i	m	e	:		
										0	5	:	0	0	m
B	a	c	k	w	a	s	h	:			O	f	f		

Information about Showerloop can be found on the information screen.

	I	n	f	o	r	m	a	t	i	o	n		
T	a	n	k										
L	e	v	e	l	:					4	5	%	
T	e	m	p	:						2		°C	
P	u	m	p	:		O	F	F					

PI control settings:

These settings make it possible to configure the system to reach the desired temperature.

P – response time to changes in temperature, the higher this value, the longer the system takes to respond to changes in temperature and this case, switching the supply of cold, hot water or vice versa.

I – time while valves open for water supply.

	P	I	c	o	n	t	r	o	l			
P	H	o	t							5	0	
P	C	o	l	d						5	0	
I	H	o	t			0	1	:	0	0	s	
I	C	o	l	d		0	1	:	0	0	s	

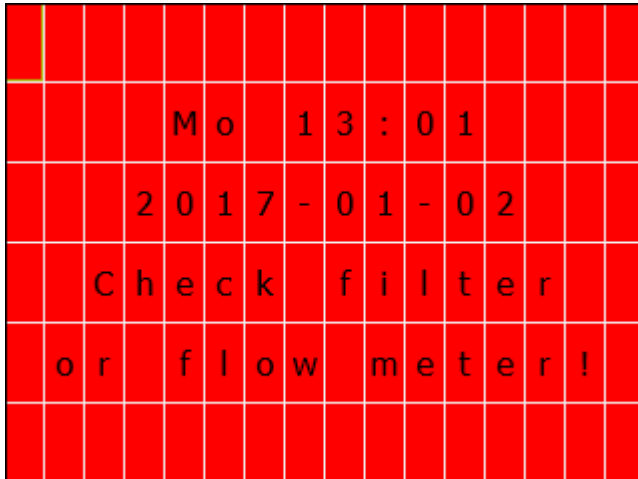
	P	I	H	e	a	t	e	r				
P										1	0	0
I						0	5	:	0	0	s	
H	e	a	t	e	r	:				O	n	
U	V	I	R	:						0	L	
R	e	s	e	t	U	V	I	R		O	f	f

Draining water from tank manually:

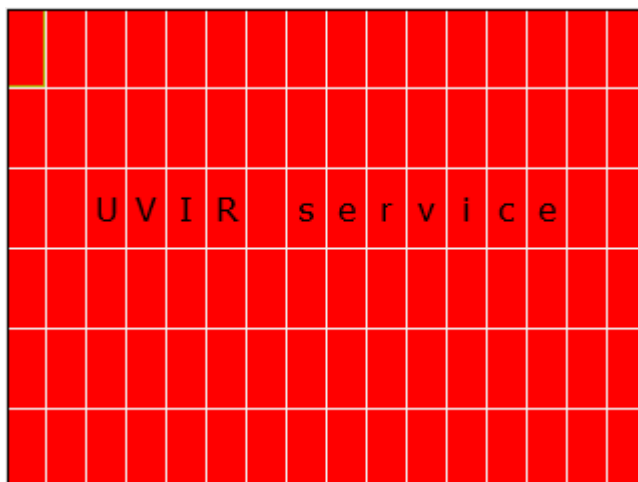
1. To empty the tank manually press ESC (more than 1sec) + Down key on Logo module.

Error messages:

1. If LOGO 0BA8 does not detect signal for 10 minutes, then an error message will appear for the user to check the pump.



- 1) When UVIR need to be changed "UVIR Service" message will be displayed.



Keys operation on LOGO 0BA8

To operate with UP, DOWN, LEFT, RIGHT keys on LOGO module, these keys should be pressed with ESC key for more than 1 second.

If the user wishes to change values (for example temperature) on the module, select desired value by reaching to value with the use of arrow keys, press OK and change the value press OK again.