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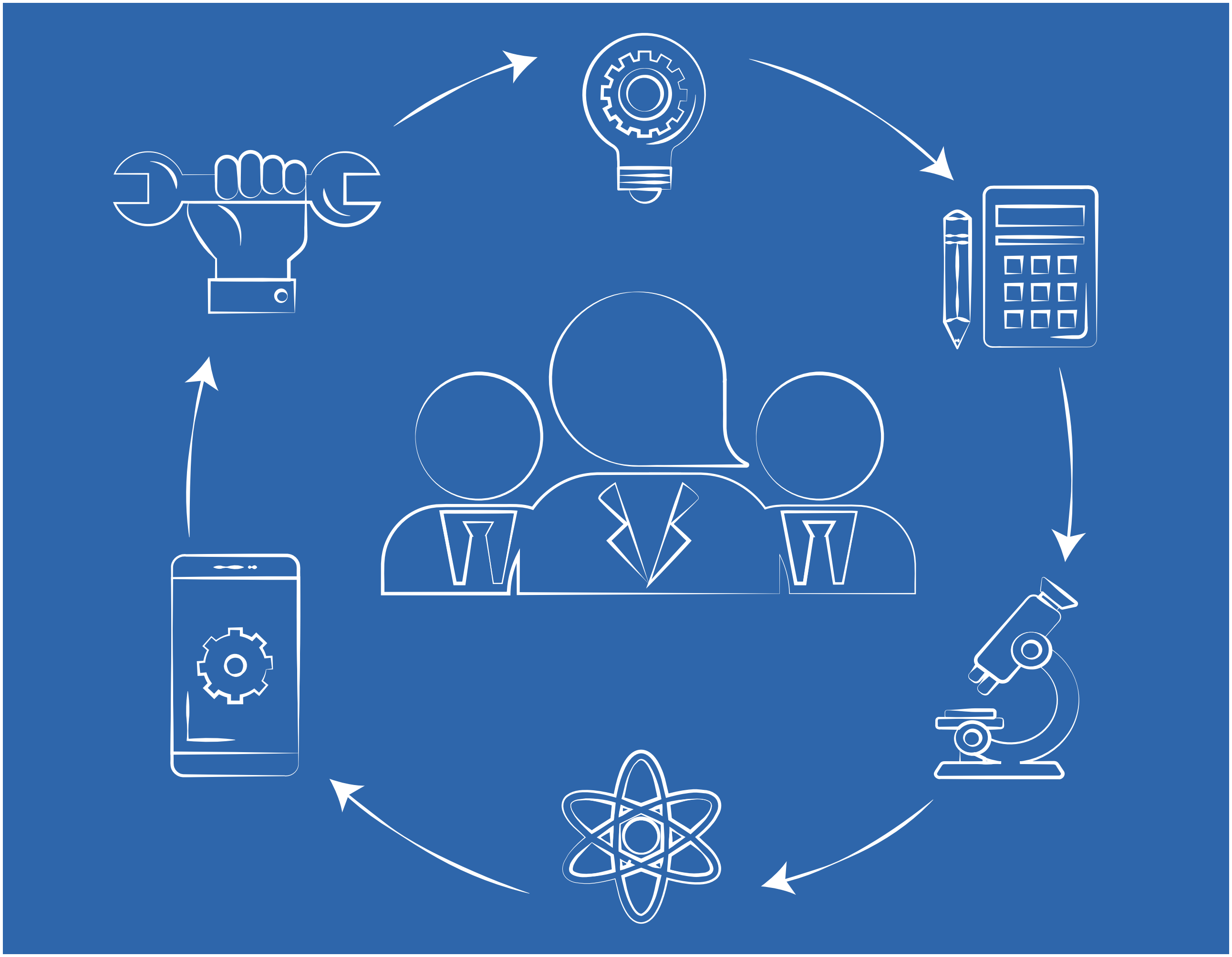

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- Internationalization of authors: 4 countries (Ecuador, South Africa, Indonesia and Malaysia).

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ESTADO DEL ARTE: MÉTRICAS DEL DESARROLLO DE SOFTWARE MÓVIL

STATE OF ART: MOBILE SOFTWARE DEVELOPMENT METRICS

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RESUMEN

El mercado de las aplicaciones móviles ha crecido considerablemente en los últimos años, debido a las diversas funcionalidades y servicios que estas ofrecen en diversos ámbitos, su desarrollo debe estar sujeto a normas de calidad que permitan asegurar una mejor experiencia para el usuario. A diferencia del software de escritorio, aún no existen estándares orientados específicamente a medir la calidad de este tipo de aplicaciones, sin embargo, varios autores han considerado la ISO 9126 como referencia para la propuesta de modelos y conjuntos de métricas. Por esta razón ha surgido la necesidad de indagar e identificar los modelos propuestos, con el objetivo de comparar las distintas métricas consideradas para determinar la calidad de una aplicación móvil. La investigación realizada es de carácter heurística, hermenéutica y descriptiva, permitiendo obtener e interpretar la información de los diferentes documentos encontrados en las principales bibliotecas digitales de carácter científico. Los resultados de la investigación demostraron que en los diferentes modelos de calidad propuestos por diversos autores consideran como métricas principales la eficiencia, comprensibilidad, adaptabilidad, interactividad, usabilidad y portabilidad. Además, se plantea que la calidad de las aplicaciones móviles se encuentra determinada por factores inherentes del software como de los dispositivos en los que se implementarán, debido a que, a diferencia de otras aplicaciones como web y escritorio, estas se encuentran limitadas por los recursos de cada uno de los terminales.

PALABRAS CLAVE

Métricas de Calidad, Software Móvil, Modelos de Calidad, Desarrollo Móvil.

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ABSTRACT

The market for mobile applications has grown considerably in recent years, due to the various functionalities and services that they provide to their users in various fields, their development must be subject to quality standards that ensure better user experience. Unlike desktop software, there are still no standards specifically aimed at measuring the quality of this type of application, however, several authors have considered ISO 9126 as a reference for the proposal of models and sets of metrics. For this reason, the need to investigate and identify the proposed models has arisen, in order to compare the different metrics considered to determine the quality of a mobile application. The research carried out is of a heuristic, hermeneutical, and descriptive nature, allowing to obtain and interpret the information of the different documents found in the main digital libraries of a scientific nature. The research results showed that in the different quality models proposed by the authors, efficiency, understandability, adaptability, interactivity, usability, and portability are considered as main metrics. In addition, it is suggested that the quality of mobile applications is determined by factors inherent to the software and the devices in which they will be implemented, because, unlike other applications such as web and desktop, these are limited by resources from each of the terminals.

KEYWORDS

Quality Metrics, Mobile Software, Quality Models, Mobile Development.

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1. INTRODUCCIÓN

Actualmente las aplicaciones móviles se han convertido en herramientas indispensables para los usuarios, su finalidad es facilitar el desarrollo de actividades cotidianas dentro de las diversas áreas tales como empresarial, entretenimiento, educación, salud, entre otras.

Como en todo software, la calidad es una de las características que siempre hay que tener presente, debido a que es uno de los factores que influye en los procesos de desarrollo de software, así como en la experiencia con el producto que recibe el usuario final (Mishra y Otaiwi, 2020). Sin embargo, actualmente no se dispone de un paradigma de software que permita asegurar la calidad del producto de software móvil (Corral *et al.*, 2015).

Padhy *et al.* (2019) señala que "las métricas de software desempeñan un papel importante en la industria del software," por esta razón varios autores han propuesto modelos y conjunto de métricas que han considerado relevantes para definir la calidad de una aplicación móvil, a partir de los atributos de la ISO/IEC 9126 tales como eficiencia, usabilidad, portabilidad entre otros.

En base a lo mencionado anteriormente se observa la necesidad de indagar e identificar los modelos propuestos con el objetivo de comparar las distintas métricas consideradas para determinar la calidad de una aplicación móvil.

2. ANTECEDENTES O ESTADO DEL ARTE

2.1. APLICACIONES MÓVILES

Tabla 1. Estado del Arte – Aplicaciones Móviles.

Año	Título del Libro	Contenido
2016	Analyzing and automatically labelling the types of user issues that are raised in mobile app reviews	"El mercado de aplicaciones móviles sigue creciendo a un ritmo muy rápido con miles de desarrolladores, miles de aplicaciones y millones de dólares en ingresos." (McIlroy *et al.*, 2016).

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2017	Aplicación de Dispositivos Móviles en la Medición de los Niveles de Radiación Ultravioleta y su Validación en el Distrito de Chulucanas Región Piura Perú	"Se denomina App a una aplicación de software que se instala en dispositivos móviles con la finalidad de facilitar al usuario la consecución de tareas, operaciones o gestiones del día a día." (Mimbela *et al.*, 2017).
2018	Studying the dialogue between users and developers of free apps in the Google Play Store	"Las aplicaciones móviles continúan ganando popularidad rápidamente en los últimos años. Las aplicaciones móviles pueden ser descargadas de tiendas de aplicaciones, como Google Play Store, que tiene más de 3.1millones de aplicaciones disponibles en julio de 2017." (Hassan *et al.*, 2018).

Fuente: elaboración propia.

De acuerdo con Hassan *et al.* (2018), McIlroy *et al.* (2016), y Mimbela *et al.* (2017), las aplicaciones móviles están enfocadas en ayudar al usuario con sus actividades diarias, tanto personales, profesionales, entretenimiento, entre otras, las mismas que pueden ser utilizadas desde dispositivos móviles como teléfonos inteligentes o tabletas. Acceder a este tipo software es muy fácil gracias a las distintas plataformas de distribución existentes para cada tipo de sistema que utilizan los dispositivos. Actualmente la comunidad que utiliza y desarrolla este tipo de aplicaciones es muy amplia, lo que ha permitido que se conviertan en herramientas indispensables para muchas áreas como empresarial, educación y salud. Rasool y Ali (2020) mencionan que "el éxito de aplicaciones móviles depende de su calidad, fiabilidad, corrección, rendimiento y satisfacción general de los usuarios."

2.1. MÉTRICAS DE CALIDAD DEL SOFTWARE MÓVIL

Tabla 2. Estado del arte – Métricas de Calidad de Software Móvil.

Año	Título del Libro	Contenido
2014	Comparación de modelos de calidad, factores y métricas	"Las métricas se definen para cada criterio de calidad, son medidas cuantitativas que indican el grado en el que está presente un atributo en el producto." (Constanzo *et al.*, 2014).
2015	A Framework for Evaluating the Software Product Quality of Pregnancy Monitoring Mobile Personal Health Records	"Las métricas de este modelo miden hasta qué punto un producto satisface las necesidades de usuarios específicos en un contexto de uso específico." (Idri *et al.*, 2015).
2016	Defining usability quality metric for mobile game prototype using software attributes	"La calidad dentro de la ingeniería de software hace referencia a la capacidad del producto de software para satisfacer los requisitos del usuario o sus expectativas." (Pavapootanont y Prompoon, 2015).

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2016	Deriving thresholds of software metrics to predict faults on open source software: Replicated case studies	"Las métricas de software tienen como objetivo reflejar la calidad interna de los sistemas de software."(Arar y Ayan, 2016).
2018	Android Quality Measurement in Metrics and Findings	"Las métricas y los hallazgos son tipos de medición de software calidad." (Sutino *et al.*, 2018).

Fuente: elaboración propia.

El desarrollo de un software de calidad en alineación a los requerimientos del cliente tiene como base la aplicación de un conjunto de métricas que permiten evaluar su calidad interna y externa. Es importante identificar las distintas perspectivas existentes acerca de la calidad del software por parte de los interesados en el proyecto, previo a la selección del modelo y conjunto de métricas, debido a que, para el usuario, la calidad puede significar sencillez de aprendizaje, mientras que para un director de proyectos o programadores la calidad puede verse reflejada como eficiencia en el desempeño y compatibilidad. Las métricas permiten realizar una serie de actividades dentro de las etapas de desarrollo y mantenimiento del software como se ilustra en la Figura 1.

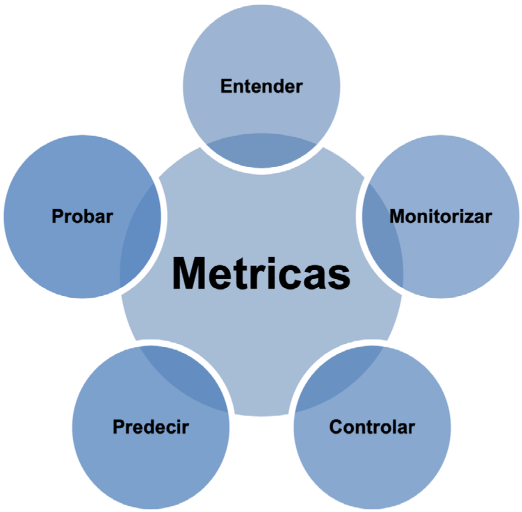

Figura 1. Funciones de las métricas.

Fuente: elaboración propia.

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2.1. MODELOS Y ESTÁNDARES DE CALIDAD A NIVEL DE PRODUCTO

Tabla 3. Modelos y estándares de calidad a Nivel de Producto.

Nombre	Características	Factores de Calidad
MSQM	"Este modelo se centra en las cualidades clave de plataformas y aplicaciones móviles… no está restringido a las cualidades de software dadas, sino que es fácilmente extensible para cualquier necesidad específica de la aplicación." (Franke *et al.*, 2012).	• Flexibilidad • Extensibilidad • Adaptabilidad • Portabilidad • Usabilidad • Eficiencia • Persistencia de Datos
PACMAD	"Los dispositivos móviles requieren modelos específicos. Se pueden agregar servicios de funcionalidad adicionales a una aplicación de software para permitir al usuario un mayor logro con la aplicación." (Saleh *et al.*, 2015).	• Efectividad • Eficiencia • Satisfacción • Capacidad de aprendizaje • Memorizabilidad • Errores • Carga cognitiva
ISO/IEC 25010 SQUARE	"Sirve como marco para garantizar que todos los aspectos de la calidad se consideren desde el punto de vista interno, externo y de calidad en el uso." (Idri *et al.*, 2015).	• Idoneidad funcional • Confiabilidad • Eficiencia en el desempeño • Operabilidad • Seguridad • Compatibilidad • Mantenibilidad • Portabilidad
ISO/IEC 9126	"Hemos desarrollado un marco para utilizar la ISO 9126, en particular su modelo de calidad externa, para hacer frente a las limitaciones de los entornos móviles que se componen principalmente en dos subcategorías" (Moumane *et al.*, 2016).	• Funcionalidad • Fiabilidad • Usabilidad • Eficiencia • Mantenimiento • Portabilidad
MAUEM	"Proporciona orientación sobre cómo y qué medir para cada atributo de usabilidad, lo que podría conducir a una evaluación de usabilidad completa para una aplicación móvil." (Saleh *et al.*, 2017).	• Eficiencia • Efectividad • Satisfacción • Capacidad de aprendizaje • Memorizabilidad • Errores • Carga cognitiva • Interrumpibilidad • Sencillez

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C&K	"Desde la definición de Chidamber y Kemerer, las métricas de OO han ganado popularidad y se las conoce brevemente como el conjunto de métricas de C & K para evaluar la calidad del software." (Gezici *et al.*, 2019).	• Mantenibilidad • Comprensibilidad • Usabilidad • Reutilización • Testabilidad • Eficiencia • Portabilidad

Fuente: elaboración propia.

El rápido crecimiento del mercado de las aplicaciones móviles ha llevado a la industria de software a plantearse modelos que permitan definir métricas para el aseguramiento de la calidad de las mismas. Muchos de los modelos toman como referencia factores de la ISO/IEC 9126 como eficiencia, portabilidad y mantenibilidad. Por otro lado, algunos modelos prestan más atención a la usabilidad, como PACMAD y MAUEM de los que resaltan la capacidad de aprendizaje y carga cognitiva.

2.1. MODELOS Y ESTÁNDARES DE CALIDAD A NIVEL DE PROCESOS

Tabla 4. Modelos y estándares de calidad a Nivel de Procesos.

Nombre	Características	Factores de Calidad
ISO/IEC 15504 SPICE	"Permite a las organizaciones aumentar la madurez de sus procesos de desarrollo de software mediante la mejora continua." (Quintal y Macías, 2020).	• Suministro • Gestión del Modelo de Ciclo de Vida • Planificación • Evaluación y Control • Medición • Análisis de Requisitos del Sistema • Aseguramiento de la Calidad
ISO/IEC 9001:2015	"El enfoque del proceso implica la definición y gestión sistemática de los procesos, y sus interacciones, con el fin de lograr los resultados previstos de acuerdo con la política de calidad y la dirección estratégica de la organización." ("ISO 9001:2015(en), Quality management systems — Requirements", s. f.).	• Alcance • Referencias normativas • Términos y definiciones • Contexto de la organización • Liderazgo • Planificación • Evaluación del desempeño

Fuente: elaboración propia.

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García menciona que "las organizaciones de software son muy conscientes de que las implementaciones de procesos de software bien definidos mejoran el desarrollo de productos de software y su calidad" (García-García *et al.,* 2019), por esta razón es importante conocer los modelos aplicados durante el desarrollo de aplicaciones móviles y como aportan a la calidad de las mismas. En la Figura 2 se puede observar las responsabilidades de la gestión de procesos de software.

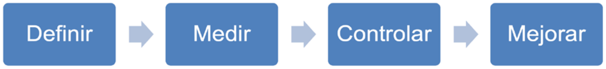

Figura 2. Responsabilidades de la gestión de procesos de software.

Fuente: elaboración propia.

3. METODOLOGÍA

La investigación es de carácter heurística, hermenéutica y descriptiva, permitiendo obtener e interpretar la información de los diferentes documentos científicos. Para efectuar la presente investigación se ha establecido varias fases las cuales se detallan en la Figura 3.

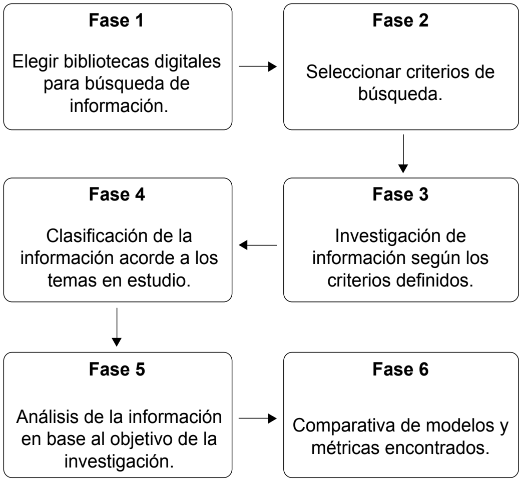

Figura 3. Funciones de las métricas.

Fuente: elaboración propia.

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3.1. BIBLIOTECAS DIGITALES

Para asegurar la fiabilidad de la información de esta investigación se ha seleccionado algunas de las principales plataformas de búsqueda de información científica las cuales se detallan en la Tabla 5.

Tabla 5. Bibliotecas Digitales.

Biblioteca	Sitio Web
Springer Link	https://link.springer.com/
ACM Digital Library	https://dl.acm.org/
IEEE Xplore Digital Library	https://ieeexplore.ieee.org/
ScienceDirect	https://www.sciencedirect.com/
ELSEVIER	https://www.elsevier.es/es

Fuente: elaboración propia.

Se ha considerado estas bibliotecas por su extensa colección de documentos de carácter científico además de indexar revistas con factor de impacto.

3.2. CRITERIOS DE BÚSQUEDA

Para facilitar la búsqueda de información se ha utilizado algunas palabras clave relacionadas al tema de métricas del desarrollo de software móvil, las cuales se detallan en la Tabla 6.

Tabla 6. Keywords.

N.º	KEYWORDS
1	mobile software quality
2	mobile app quality
3	mobile app quality metrics
4	mobile app quality metrics
5	mobile app quality factors
6	mobile application quality criteria
7	mobile software quality criterio
8	quality evaluation mobile applications
9	quality evaluation mobile software

Fuente: elaboración propia.

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Con los resultados obtenidos se procederá a la clasificación de los documentos para obtener un conjunto más reducido de artículos y que se acerquen más a los temas en estudio.

Se continua con al análisis del conjunto de artículos clasificados con el objetivo de extraer las contribuciones de los autores acordes a la investigación y desarrollar el estado del arte.

4. RESULTADOS

Definir la calidad de un software móvil requiere el análisis de diversas métricas que estén acorde a su contexto, debido a que este tipo de software se desarrolla teniendo presente el campo de aplicación y las limitaciones de los dispositivos donde se utilizarán, como batería, capacidad de procesamiento, memoria, dimensiones de pantalla, red, ente otras, tal como se evidencia en la las investigaciones de otros autores en la Tabla 7.

Tabla 7. Métricas consideradas para la calidad de aplicaciones móviles.

Investigaciones	Métricas consideradas
(Syer *et al.*, 2015)	Dependencia de Plataforma Móvil (SO)
(Noei *et al.*, 2017)	Interfaz Rendimiento Tamaño
(Mendonça *et al.*, 2019)	Energia Tiempo de ejecución Disponibilidad Conexión Rendimiento

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(Pandey *et al.*, 2019)	Funcionalidad Interfaz Rendimiento Compatibilidad Conexión Tiempo de respuesta, Energía Seguridad
(Maia *et al.*, 2019)	Energía Memoria Almacenamiento Rendimiento, Pantalla, Dependencia de red, Usabilidad Mantenibilidad Portabilidad Eficiencia Compatibilidad Satisfacción
(Xiang *et al.*, 2020)	Rejuvenecimiento del software Confiabilidad Disponibilidad
(Soui *et al.*, 2020)	Interfaz de Usuario Móvil (MUI) Interacción Usabilidad Eficacia
(Rodrigues *et al.*, 2020)	Funcionalidad Estética Entretenimiento Interactividad
(Biørn-Hansen *et al.*, 2020)	Multiplataforma Rendimiento

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(Davalbhakta *et al.*, 2020)	Funcionabilidad Amigable Interactiva Accesibilidad

Fuente: elaboración propia.

La ausencia de estas características puede impactar en menor o mayor grado la calidad, y a pesar de que existen varios factores importantes que se debe considerar al momento de desarrollar una aplicación móvil, aún no existe un estándar específico para este tipo de software.

En la Tabla 8 se puede visualizar un análisis realizado a partir de las investigaciones de las Tablas 3 y 7 para comprender la relación existente entre las métricas y modelos propuestos por otros investigadores.

Tabla 8. Métricas de calidad y su relación con modelos propuestos.

Métricas de calidad	**Modelo MSQM**	**Modelo PACMAD**	**ISO/IEC 9126**	**ISO/IEC 25010**	**Modelo MAUEM**	**Modelo C&K**	**TOTAL**
Portabilidad	x		x	x		x	4
Funcionabilidad			x	x			1
Eficiencia	x	x	x	x	x	x	6
Efectividad		x			x		2
Confiabilidad			x	x			2
Compatibilidad	x			x		x	3
Flexibilidad	x						1
Mantenibilidad			x	x		x	3
Comprensibilidad		x			x	x	3
Operabilidad				x			1
Seguridad				x			1
Persistencia de datos	x				x		2
Adaptabilidad	x						1

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Accesibilidad							0
Interactividad							0
Rendimiento							0
Dependencia de Red							0
Almacenamiento							0
Extensibilidad	x						1
Carga Cognitiva		x			x		2

Fuente: elaboración propia.

La eficiencia, compatibilidad, comprensibilidad, y portabilidad son las métricas que más relevancia tienen en todos los normas y modelos propuestos, resaltando de ellos la ISO/IEC 25010 que posee gran parte de estos atributos, a pesar de ello no evalúa factores externos propios de los dispositivos móviles como la capacidad de rendimiento, almacenamiento, dependencia de red, y características de la interfaz como accesibilidad e interactividad que autores como Davalbhakta *et al.* (2020), Noei *et al.* (2017), y Soui *et al.* (2020) consideran de gran importancia.

4.1. MÉTRICAS DE CALIDAD PARA SOFTWARE MÓVIL

Para determinar la calidad de las aplicaciones móviles se deben evaluar diversos factores propios del software como de los dispositivos en los que se implementarán, debido a que, a diferencia de otras aplicaciones como web y escritorio, estas se encuentran limitadas por los recursos de cada uno de los terminales.

Las normas, modelos y conjunto de métricas propuestos por diversos autores consideran que una aplicación móvil de calidad utiliza de forma óptima los recursos del dispositivo como memoria, almacenamiento, pantalla y red para mejorar la experiencia de usuario.

La interacción y accesibilidad son características de calidad que se deben considerar en las aplicaciones móviles, para ello los componentes de la interfaz de usuario deben estar bien distribuidos debido a

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que las pantallas que ofrecen los dispositivos son de pequeñas dimensiones, obteniendo así una interfaz amigable para el cliente.

Otra característica de calidad y que va ligada a la interfaz, es la carga cognitiva que los usuarios experimentan al momento de utilizar una aplicación, esta debe ser mínima, es decir no requerirá de mucho esfuerzo para utilizar el software o recordar cómo funciona.

El mercado de las aplicaciones móviles a la fecha de esta investigación se encuentra dividido en dos grandes plataformas, iOS y Android, esta es la particular razón por la que las aplicaciones móviles deben considerar la característica de ser portables y multiplataforma sin que esto afecte de manera significativa el rendimiento y eficiencia de la misma.

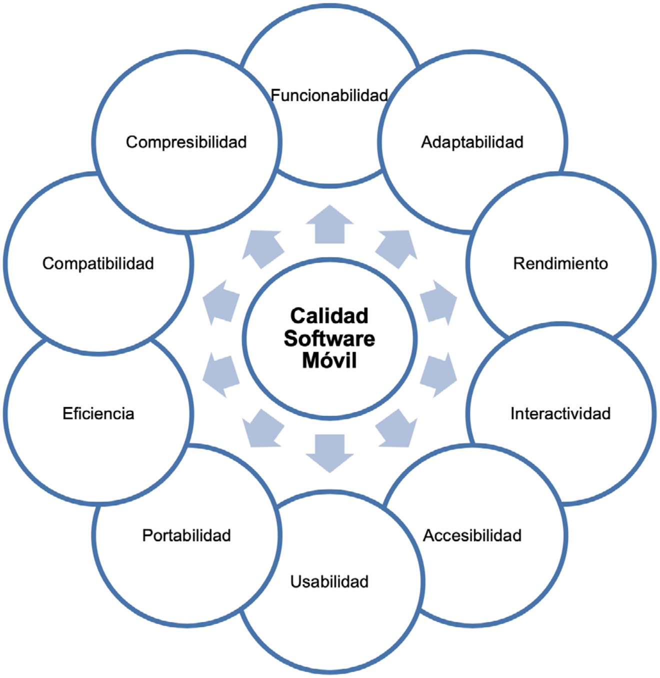

Figura 4. Métricas de calidad para Software Móvil.

Fuente: elaboración propia.

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4. DISCUSIÓN

La investigación realizada nace ante la necesidad de conocer las métricas de calidad utilizadas para el desarrollo de software móvil y mediante el análisis de los documentos expuestos por diversos autores, se ha logrado responder esta incógnita.

Olivera y Paz (2018) mencionan que la ISO/IEC 9126 posee una gran variedad de métricas utilizadas para medir la calidad del software tales como la portabilidad, usabilidad y eficiencia, por esta razón varios investigadores la utilizan como base para la propuesta de modelos y métricas que permitan determinar la calidad de las aplicaciones móviles. Sin embargo, Maia *et al.* (2019) plantean la necesidad de considerar otros factores propios de los dispositivos que ejecutan este tipo de aplicaciones, tales como memoria, red, almacenamiento y pantalla debido a que influyen en el funcionamiento de las mismas. De igual manera, Soui *et al.* (2020) consideran que la pantalla de los dispositivos como teléfonos inteligentes es una limitante para las apps, razón por la que considera la interactividad y accesibilidad proporcionada por la interfaz como métricas importantes en la calidad de un aplicativo móvil.

Considerando las opiniones de los diversos autores se puede definir que las métricas de calidad para las aplicaciones móviles son muy variables por los diversos contextos en las que son utilizadas. Por esta razón se cree necesario para futuros trabajos la implementación de estándares o modelos que permitan reunir las métricas desde las perspectivas mencionadas.

5. CONCLUSIONES

Con base a los resultados obtenidos en la presente investigación se puede concluir mencionado que los diversos modelos y conjuntos de métricas propuestos por otros autores toman como referencia los factores de calidad planteados por la ISO/IEC 9126.

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Otros autores sugieren tomar en cuenta factores que no se mencionan dentro de los modelos propuestos, como características propias de los dispositivos ya que se consideran que estas también influyen en la calidad de una aplicación.

Uno de los estándares que aborda la mayor cantidad de métricas propuestas por los autores es la ISO/IEC 25010 también denominada SQUARE la cual garantiza la calidad interna, externa y de uso, sin embargo, no es norma específicamente diseñada para el análisis de la calidad de aplicaciones móviles.

REFERENCIAS BIBLIOGRÁFICAS

Arar, Ö. F., y Ayan, K. (2016). Deriving thresholds of software metrics to predict faults on open source software: Replicated case studies. *Expert Systems with Applications, 61,* 106-121. https://doi.org/10.1016/j.eswa.2016.05.018

Biørn-Hansen, A., Rieger, C., Grønli, T.-M., Majchrzak, T. A., y Ghinea, G. (2020). An empirical investigation of performance overhead in cross-platform mobile development frameworks. *Empirical Software Engineering, 25*(4), 2997-3040. https://doi.org/10.1007/s10664-020-09827-6

Constanzo, M. A., Casas, S. I., y Marcos, C. A. (2014). Comparación de modelos de calidad, factores y métricas. *Informe Científico Técnico UNPA, 6*(1), 1-36. https://doi.org/10.22305/ict-unpa.v6i1.89

Corral, L., Sillitti, A., y Succi, G. (2015). Software assurance practices for mobile applications. *Computing, 97*(10), 1001-1022. https://doi.org/10.1007/s00607-014-0395-8

Davalbhakta, S., Advani, S., Kumar, S., Agarwal, V., Bhoyar, S., Fedirko, E., Misra, D. P., Goel, A., Gupta, L., y Agarwal, V. (2020). A Systematic Review of Smartphone Applications Available for Corona Virus Disease 2019 (COVID19) and the Assessment of their Quality Using the Mobile Application Rating Scale (MARS). *Journal of Medical Systems, 44*(9), 164. https://doi.org/10.1007/s10916-020-01633-3

https://doi.org/10.17993/3ctecno/2021.v10n3e39.17-37

Franke, D., Kowalewski, S., y Weise, C. (2012). A Mobile Software Quality Model. En *2012 12th International Conference on Quality Software*, 154-157. https://doi.org/10.1109/QSIC.2012.49

García-García, J. A., Enríquez, J. G., y Domínguez-Mayo, F. J. (2019). Characterizing and evaluating the quality of software process modeling language: Comparison of ten representative model-based languages. *Computer Standards & Interfaces, 63,* 52-66. https://doi.org/10.1016/j.csi.2018.11.008

Gezici, B., Tarhan, A., y Chouseinoglou, O. (2019). Internal and external quality in the evolution of mobile software: An exploratory study in open-source market. *Information and Software Technology, 112*, 178-200. https://doi.org/10.1016/j.infsof.2019.04.002

Hassan, S., Tantithamthavorn, C., Bezemer, C.-P., y Hassan, A. E. (2018). Studying the dialogue between users and developers of free apps in the Google Play Store. *Empirical Software Engineering, 23*(3), 1275-1312. https://doi.org/10.1007/s10664-017-9538-9

Idri, A., Bachiri, M., y Fernández-Alemán, J. L. (2015). A Framework for Evaluating the Software Product Quality of Pregnancy Monitoring Mobile Personal Health Records. *Journal of Medical Systems, 40*(3), 50. https://doi.org/10.1007/s10916-015-0415-z

ISO 9001:2015(en), Quality management systems—Requirements. (s. f.). https://www.iso.org/obp/ui

Maia, V., Gonçalves, T. G., y da Rocha, A. R. C. (2019). Quality Characteristics of Mobile Applications: A Survey in Brazilian Context. *Proceedings of the XVIII Brazilian Symposium on Software Quality,* 109–118. https://doi.org/10.1145/3364641.3364654

McIlroy, S., Ali, N., Khalid, H., y E. Hassan, A. (2016). Analyzing and automatically labelling the types of user issues that are raised in mobile app reviews. *Empirical Software Engineering, 21*(3), 1067-1106. https://doi.org/10.1007/s10664-015-9375-7

Mendonça, J., Andrade, E., y Lima, R. (2019). Assessing mobile applications performance and energy consumption through experiments and Stochastic models. *Computing, 101*(12), 1789-1811. https://doi.org/10.1007/s00607-019-00707-6

Mimbela, N. J. D., Rubio, L. R., Jiménez, J. C., y Domínguez, Y. V. (2017). Aplicación de Dispositivos Móviles en la Medición de los Niveles de Radiación Ultravioleta y su Validación en el Distrito de Chulucanas Región Piura Perú. *Revista Ingenierías USBMed, 8*(1), 49-55.

Mishra, A., y Otaiwi, Z. (2020). DevOps and software quality: A systematic mapping. *Computer Science Review, 38*, 100308. https://doi.org/10.1016/j.cosrev.2020.100308

Moumane, K., Idri, A., y Abran, A. (2016). Usability evaluation of mobile applications using ISO 9241 and ISO 25062 standards. *SpringerPlus, 5*(1), 548. https://doi.org/10.1186/s40064-016-2171-z

Noei, E., Syer, M. D., Zou, Y., Hassan, A. E., y Keivanloo, I. (2017). A study of the relation of mobile device attributes with the user-perceived quality of Android apps. *Empirical Software Engineering, 22*(6), 3088-3116. https://doi.org/10.1007/s10664-017-9507-3

Olivera, C., y Paz, F. (2018). A Web System and Mobile App to Improve the Performance of the Usability Testing Based on Metrics of the ISO/IEC 9126 and Emocards. En A. Marcus & W. Wang (Eds.), *Design, User Experience, and Usability: Theory and Practice* (pp. 479-495). Springer International Publishing. https://doi.org/10.1007/978-3-319-91797-9_35

Padhy, N., Panigrahi, R., y Neeraja, K. (2019). *Threshold estimation from software metrics by using evolutionary techniques and its proposed algorithms, models.* Evolutionary Intelligence. https://doi.org/10.1007/s12065-019-00201-0

Pandey, M., Litoriya, R., y Pandey, P. (2019). Novel Approach for Mobile Based App Development Incorporating MAAF. *Wireless Personal Communications, 107*(4), 1687-1708. https://doi.org/10.1007/s11277-019-06351-9

Pavapootanont, S., y Prompoon, N. (2015). Defining usability quality metric for mobile game prototype using software attributes. En *2015 6th IEEE International Conference on Software Engineering and Service Science (ICSESS)*, 730-736. https://doi.org/10.1109/ICSESS.2015.7339161

Quintal, C., y Macías, J. A. (2020). *Measuring and improving the quality of development processes based on usability and accessibility.* Universal Access in the Information Society. https://doi.org/10.1007/s10209-020-00726-7

Rasool, G., y Ali, A. (2020). Recovering Android Bad Smells from Android Applications. *Arabian Journal for Science and Engineering, 45*(4), 3289-3315. https://doi.org/10.1007/s13369-020-04365-1

Rodrigues, A. T., Sousa, C. T., Pereira, J., Figueiredo, I. V., y Lima, T. de M. (2020). *Mobile Applications (Apps) to Support the Hepatitis C Treatment: A Systematic Search in App Stores*. Therapeutic Innovation & Regulatory Science. https://doi.org/10.1007/s43441-020-00201-8

Saleh, A., Isamil, R. B., y Fabil, N. B. (2015). Extension of pacmad model for usability evaluation metrics using Goal Question Metrics (GQM) approach. *Journal of Theoretical and Applied Information Technology, 79*(1). http://www.jatit.org/volumes/Vol79No1/11Vol79No1.pdf

Saleh, A., Ismail, R., y Fabil, N. (2017). Evaluating Usability for Mobile Application: A MAUEM Approach. *Proceedings of the 2017 International Conference on Software and e-Business*, 71–77. https://doi.org/10.1145/3178212.3178232

Soui, M., Chouchane, M., Mkaouer, M. W., Kessentini, M., y Ghedira, K. (2020). Assessing the quality of mobile graphical user interfaces using multi-objective optimization. *Soft Computing, 24*(10), 7685-7714. https://doi.org/10.1007/s00500-019-04391-8

Sutino, Q. L., Maryamah, y Rochimah, S. (2018). Android Quality Measurement in Metrics and Findings. En *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, 365-370. https://doi.org/10.1109/EECCIS.2018.8692832

Syer, M. D., Nagappan, M., Adams, B., y Hassan, A. E. (2015). Studying the relationship between source code quality and mobile platform dependence. *Software Quality Journal, 23*(3), 485-508. https://doi.org/10.1007/s11219-014-9238-2

Xiang, J., Weng, C., Zhao, D., Andrzejak, A., Xiong, S., Li, L., y Tian, J. (2020). Software aging and rejuvenation in android: New models and metrics. *Software Quality Journal, 28*(1), 85-106. https://doi.org/10.1007/s11219-019-09475-0

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INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID

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ABSTRACT

Escalating electrical energy usage and costs over the past few years has resulted in large utility bill expenses that municipalities are struggling to pay-off to National Energy Suppliers. Furthermore, some energy suppliers are struggling to meet the demand for more energy due to a variety of factors. The challenge therefore exists in identifying viable alternative power generation strategies for local municipalities to reduce their current electrical energy expenses or to provide limited power to their community when disconnected from the National Grid. An environmentally friendly renewable energy strategy method could be used to supplement the current energy requirements of a municipality during months of high energy demand. The main focus of this study will be on a small town in the Free State province of South Africa, called Koffiefontein. A battery-based solar PV system was designed in the Homer software and chosen as the renewable energy strategy to supplement the current energy needs of Koffiefontein due to its performance and cost effectiveness. The initial implementation cost of the system is $ 42 995 649.95. The cost of energy for the PV system suggested for Koffiefontein houses is $ 0.40/kWh with the yearly electricity production of 27 661 kWh. The payback period of the system is 45.3 years. The municipality needs to consider installing battery-based solar PV system to supply businesses in Koffiefontein during their high demanding hours and during load shedding as the system indicates an affordable cost of energy with high yearly production.

KEYWORDS

Solar PV Systems, Wind Turbine Systems, Load Shedding, Energy Audit.

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1. INTRODUCTION

Electricity supply in South Africa (SA) has long been the domain of the National Energy Supplier, called Eskom (Nehrir, 2011). Eskom supplies 96% of electricity in SA (Alfreds, 2018). Eskom and municipalities both distribute electricity to consumers; the distribution function is shared between them (Eskom, 2018). It is a major source of income for municipalities that supply electricity to households and businesses (South African Government, 2011). Eskom supplies the licensed municipalities in bulk at a pre-determined tariff, then the municipality re-sells electricity to the end users within their municipal borders at a mark-up. There are municipalities which are struggling to pay Eskom the amount of money owed due to low revenue collection from electricity e.g. Matjabeng local Municipality is currently indebted to Eskom for almost 2 Billion Rand ($ 105 654 156), part of which has been outstanding and in escalation since October 2007 (Eskom, 2018). Energy autonomy is an option being seriously considered now more than ever before and for good reasons.

The main aim of this study is to investigate alternative power generation strategies for local municipalities in order to enable more autonomy and that can help to reduce the pressure placed on the National Gird. This paper will discuss the importance of renewable energy resources. Data requirements for Homer will be analyzed and simulation results of two main strategies (solar and wind) will be presented. The conclusions end the discussion.

1.1. CONTEXT THAT NECESSITATES ALTERNATIVE STRATEGIES

The demand for power keeps growing at an alarming rate while supply trails behind. This leads to the implementation of load shedding initiatives to keep the country illuminated. When there is not enough electricity available to meet the demand for all Eskom customers, it could be necessary to interrupt supply to certain areas; this is called load shedding (Davidson, 2014). Load shedding is defined as a coordinated set of controls that decreases the electric load in one part of the system to restore the overall system back to its normal operation conditions (Swart, 2018).

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In November 2007, load shedding hit SA for the first time, disrupting businesses, closing mining operations and affecting households (Coetze & Mart-Mari, 2016). The national power grid again came under severe constrains during the 2013/2014 summer maintenance program, requiring Eskom to implement load shedding again. Eskom implemented 99 days of load shedding in 2015, causing a decrease in manufacturing and mining output, dragging down economic growth (Coetze & Mart-Mari, 2016).

Renewable and clean alternative power generation technologies can play an important role in mitigating these occurrences of load shedding. Increased global public awareness of the need for environmental protection and desire for less dependence on fossil fuels for energy production is also required (Nehrir, 2011). SA has to consider alternative power generation strategies, such as solar and wind energies, to keep up with the growing demand and to enable a better level of sustainability (Nehrir, 2011).

SA has one of the best solar irradiances in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally. The average daily solar radiation in SA is between 4.5 and 6.5 kWh/m2/day (Niselow, 2019). In terms of SA's theoretical wind potential, research from the Council for Scientific and Industrial Research suggest that to generate the equivalent of SA's current electricity demand, only 0.6% of the available SA's land mass would have to be dedicated to wind farms (Nehrir, 2011). The two main alternative strategies for this study focus on the use of wind and solar farms as possible supplements to the current energy needs of one town in the Letsemeng Local Municipality in the Free State Province of SA.

2. METHOD

This research is focused on one town in the Letsemeng Local Municipality, located in the Free State Province of SA, which is Koffiefontein. The objective of this research is to:

1. Obtain the energy usage bills from Eskom to determine what energy needs to be supplemented.

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2. Determine the number of homes/businesses that contribute to this bill, to determine if both or just one can be supplemented.

3. Recommend an appropriate renewable energy strategy (solar or wind) for the identified municipality.

The energy bills from Eskom to the municipality are obtained at the main meter of Eskom in each town. This bill indicates power consumption of the municipality for a certain month and the Notified Maximum Demand. For winter months, the energy is classified into two groups: the low and high season energy and they differ in charges.

An energy audit is conducted to determine the energy required by homes and businesses in the two towns. Audit levels clearly differ in respect of their set of objectives, scope of tasks and powers and the related tools (Palyi, 2015). A novel approach would involve using Google Maps as a tool to determine the number of households and businesses that contribute to the present energy demand. This forms a basic level audit.

Household neighborhoods are identified by swimming pools, sports grounds and schools. Businesses would be identified by the nearby presence of government departments of public buildings. This is then correlated to the amount of electrical energy that was sold to residential and industrial businesses for the past year. This helps to identify months of high energy usage. This data is then correlated to the weather data (solar radiance and wind speed per month) that has been obtained for the past 10 years in order to determine if a solar or wind farm is more suitable. After comparing the annual weather data with the monthly energy consumption from the municipality, an alternative power generation method can be suggested. Supplementary energy could be provided during high demanding hours of businesses and when government departments and schools are operative.

The Homer program can be used for simulating the output power of the two strategies with the given weather data. This software has been used both to analyze the off-grid electrification issues in

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the developed as well as developing countries (Sen, 2013). Solar radiation data, wind speed data and electricity consumption of the municipality needs to be used as input data to Homer. A cost analysis and payback period are then computed.

2.1. DATA REQUIREMENTS

During the audit, the following identification criteria was used: household neighborhoods were identified by the presence of a school (sports ground or label indication). Businesses were identified by the presence of a government building or label indication. The results of the audit indicated that Koffiefontein consist of 2038 houses and 113 businesses, with the houses consuming more energy than businesses.

The results of the audit were correlated to the municipal electricity sales that are shown in Figure 1. June 2016 has the highest energy consumption for Koffiefontein houses, therefore the energy consumption obtained for June 2016 is used to create a daily load profile for Homer. For the year 2016, Koffiefontein had a total revenue collection of R 9 277 146 ($ 613 767), of which R 6 893 384 ($ 456 059) was collected from houses and R 2 383 761 ($ 157 707) was collected from businesses.

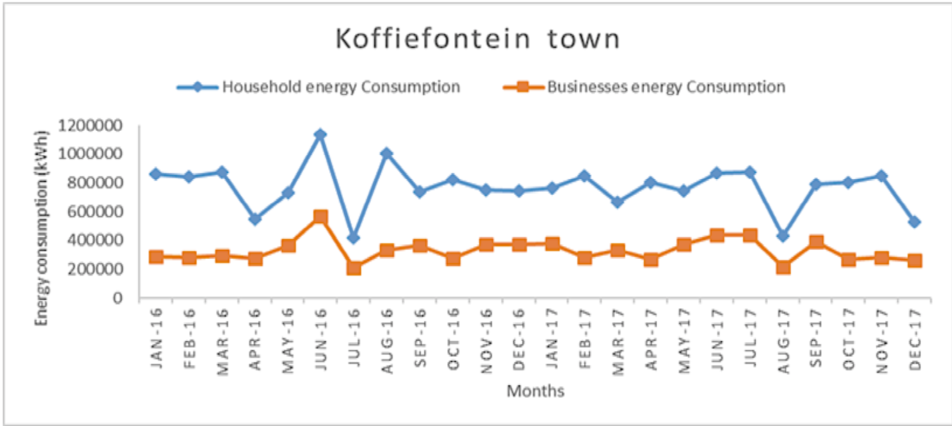

Figure 1. Total energy consumption of Koffiefontein town.

Source: own elaboration.

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Energy consumption data obtained from the municipality is in months. To convert the energy consumption to daily consumption it was firstly converted to weekly consumption using equation 1.

$$\text{Weekly energy consumption} = \frac{Monthly\ energy\ consumption\ (kWh)}{4\ Weeks} \tag{1}$$

$$= \frac{1\,135\,572.98}{4}$$

$$= 283\,893.245\ \text{kWh}$$

The total daily energy consumption is then 40 556. 171 kWh (weekly divide 7) and the daily energy consumption per house is then 19.9 kWh (total daily divide 2038). The daily usage of an average household in Koffiefontein town is used to design a 24-hour electricity consumption required as input data for Homer. The load peak demand for the average house in Koffiefontein is 2 kW. When summing the hourly usage for 24 hours, as indicated in Figure 2, then a total daily energy consumption of 19.9 kWh is obtained. The peak load requirement decides the size, structure and architecture of the proposed system (Belu, 2014). The size of the alternative energy system should consider the month of June 2016 which is the highest energy consuming month for Koffiefontein. Homer software is used to design a system for 1 house in Koffiefontein town. The results can then be scaled to cover all 2038 houses in Koffiefontein.

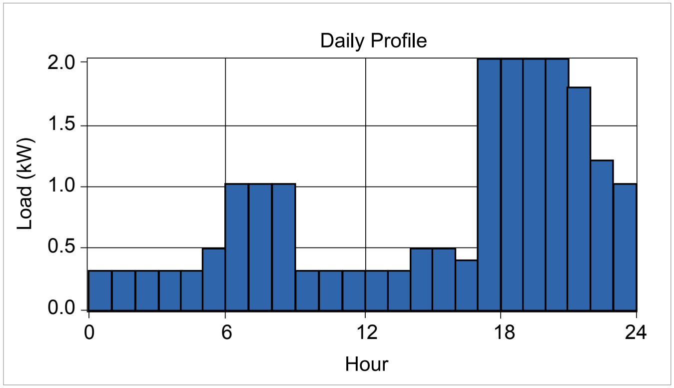

Figure 2. Hourly energy consumption of an average sized home in Koffiefontein.

Source: own elaboration.

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3. RESULTS

3.1. RESULTS FOR A SOLAR ENERGY SYSTEM

Solar radiation data is one of the important inputs that is required by Homer when doing simulations for solar PV systems. Figure 3 indicates the solar radiation data that was obtained from the Pulida solar plant located about 20 minutes' drive outside Jacobsdal, a small rural village in the Free State Province of South Africa. This data was collected in Jacobsdal town which is the nearest town to Koffiefontein because there is no solar plant in Koffiefontein. The scaled annual average of the site is indicated to be 6.06 kWh/m²/d, this value is calculated automatically by Homer.

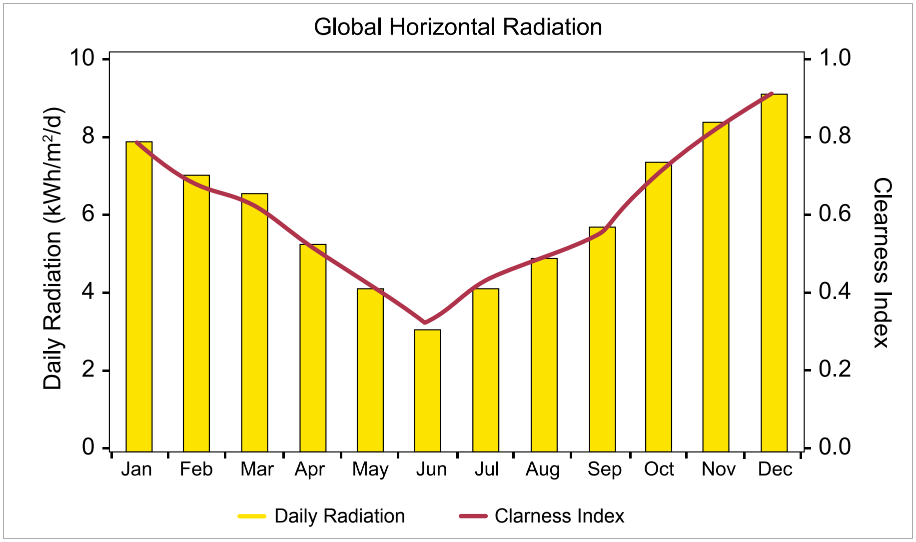

Figure 3. Solar radiation graph from HOMER based on the data from Jacobsdal.

Source: own elaboration.

Figure 4 shows the proposed battery-based solar PV system to be used to supply an averaged sized home in Koffiefontein. The PV panels have no tracking device and they were modelled with a slope of

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30 degree. The following individual PV panel sizes were considered in integer steps of one kW from 1-20 kW. The price of a 1 kW PV panel was considered to be R 7 592 ($ 210 96). The operation and maintenance (O&M) cost of the solar PV panels is assumed to be 1.56 % of the capital cost (Garni, 2017). 58 Ah Trojan T-105 battery was considered for this study. The individual sizes were considered in integer steps of one Ah from 1-40 Ah. The price of the battery was taken to be R 2 894 ($ 189) with the O&M cost assumed to be 2% of the capital cost of the battery (Koko, 2014).

A 5-kW inverter was considered to meet the peak demand of the load. The price of the pure sine wave inverter which is a Bi-Directional designed to obtain optimum inverter AC power from an installed DC battery system is found to be R 29 599 ($ 1 958). The O&M cost is assumed to be 1% of the capital cost (Koko, 2014). The typical lifespan of the converter is considered to be 15 years (Koko, 2014). The load demand of the studied averaged sized home is found to be 20 kWh/day, as obtained from the municipality. During Homer simulation, the daily random variation of 10% was considered since it is impossible for the daily load demand to be constant throughout the year. The system indicated in Figure 4 has an electricity production of 27,661 kWh/year as indicated in Figure 5.

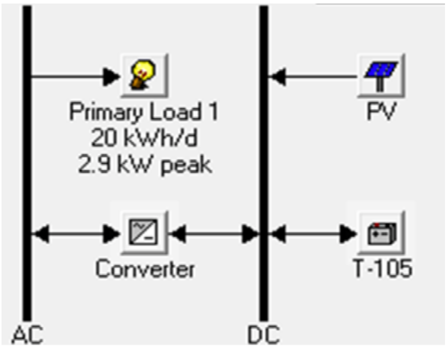

Figure 4. Proposed solar PV system to supply 1 house in Koffiefontein.

Source: own elaboration.

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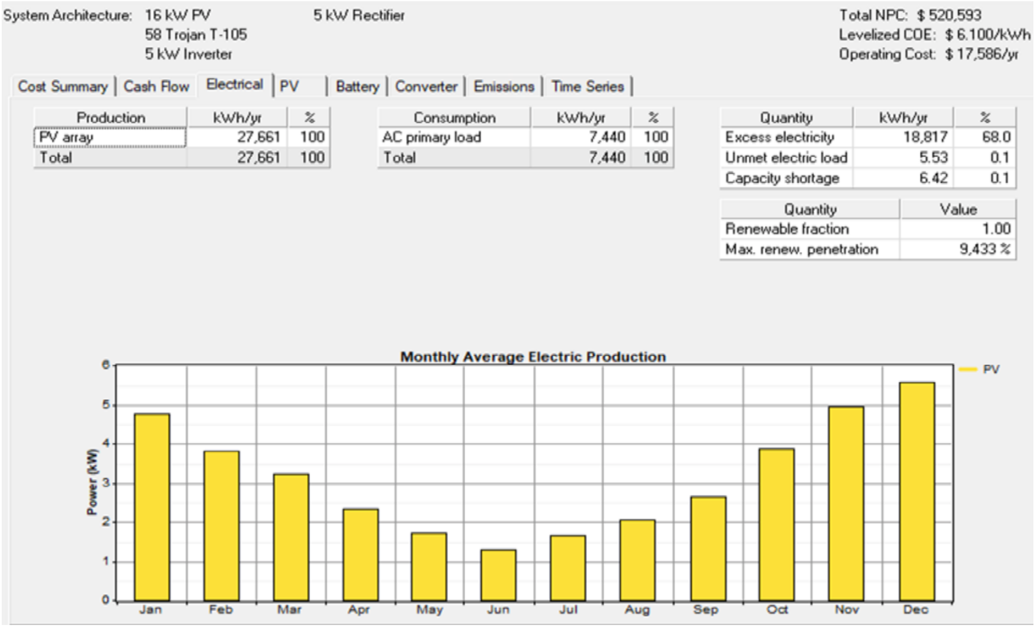

Figure 5. Yearly electricity production.

Source: own elaboration.

This system consists of a PV of size 16 kW, 58 Trojan T- 105 battery which are connected in 2 batteries per string. Excess electricity for this system is 18,817 kWh/year. This is found to be 68% of the overall generated PV electrical energy. Hence, only 32% of the generated PV electrical energy has been utilized. Since this excess electricity is not utilized for the load demand, the municipality can sell it into the Eskom utility grid to generate more revenue.

3.2. RESULTS FOR A WIND SYSTEM

For this study, the wind data was collected from one of the South African Weather Services station in Fauresmith (Free State). This town is located 54.5 km away from Koffiefontein. The wind speed data was collected at different times of the day, this data can help to suggest if a wind renewable energy system

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would be able to supplement the current energy needs of the two towns. Figure 6 indicates the wind speed data obtained at 20:00 pm. Data collected at 20:00 pm was chosen because when most of the people are back from work and schools (between 17:00 pm and 21:00 pm), the peak load demand takes place. The annual average wind speed is 1.53 m/s at an anemometer height of 10 m.

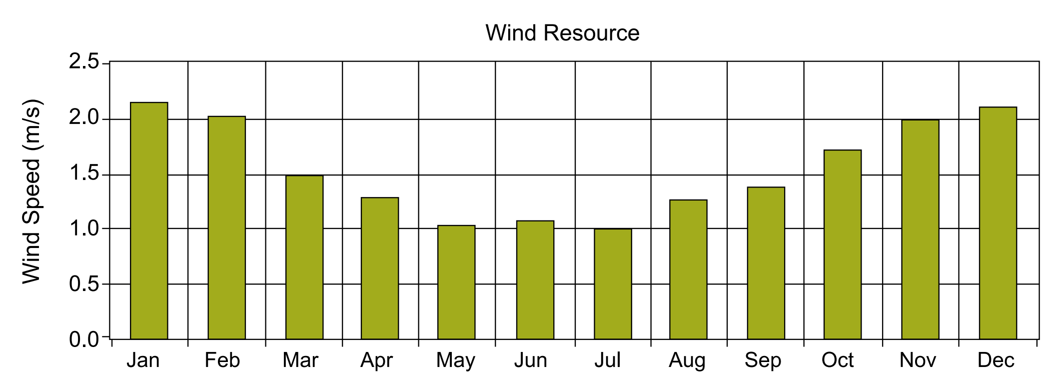

Figure 6. Wind speed data obtained at 20:00 pm from Fauresmith.

Source: own elaboration.

Figure 7 shows the proposed battery-based wind turbine system to be used to supply an averaged sized home in Koffiefontein. This system indicates the primary load of 20 kWh/d which is used as the electricity consumption input for an average house in Koffiefontein. During Homer simulation, wind turbine system sizes were considered in steps of 10 kW integer values ranging from 0 to 23 wind turbines. The capital cost of the generic 10 kW was assumed to be R 465 320 ($ 307 85) and the O&M of the system was taken as 2% of the capital (Koko, 2014). The lifetime of the system was assumed to be 25 years. The following individual sizes were considered for the Trojan T-105 battery: steps of one Ah integers from 3501-3520 Ah. The same capital cost of the battery used for the PV system was considered.

Figure 8 indicates the yearly electricity production results of the battery-based wind turbine system. This system has an electricity production of 1 907 kWh/year. This has resulted in an excess electricity of 3.26

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kWh/year (0.171%) with an unmet electricity load of 5.21 kWh/year. This system consists of 170 kW wind turbine systems and 7012 Trojan T-105 batteries which are connected in 2 batteries per string.

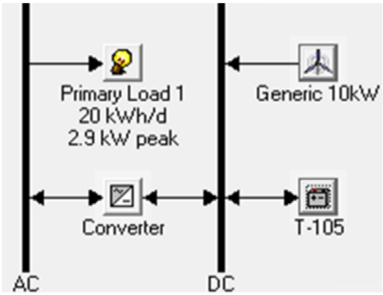

Figure 7. Proposed wind turbine system to supply 1 house in Koffiefontein.

Source: own elaboration.

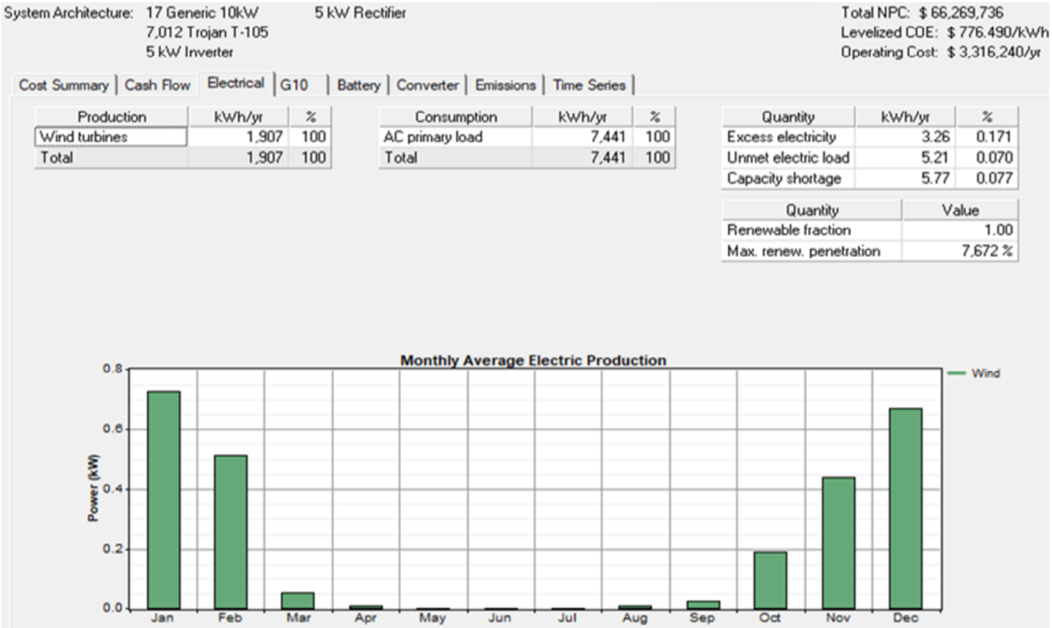

Figure 8. Yearly electricity production of the wind turbine system.

Source: own elaboration.

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Before deciding which system to install for houses in Koffiefontein, payback period of each system suggested by Homer for Koffiefontein houses is determined. To determine the payback period of the municipality, revenue collect from household electricity sales, total cost of the PV system which is R 649 883 554 ($ 42 995 649) for 2038 houses is used and total cost of the wind turbine system which is R 57 538 299 664 ($ 380 067 671 2) for 2038 houses is also used.

An averaged sized home in Koffiefontein requires 16 kW PV panels and 170 kW wind turbine system to meet its load demand. To determine the size of the PV panels and wind turbine system required to meet the load demand of the total number of houses which is 2038, total number of houses which is 2038 is multiplied by the 16 kW PV panels and 170 kW wind turbine system respectfully, this gives a total of 32 608 kW PV panels and the wind turbine size is 346 460 kW. Equation 2 is used to calculate the payback period of the municipality for both the battery-based wind turbine system and battery-based solar PV system for 2038 houses. The payback period for the battery-based solar PV system is 45.3 years, this is the maximum period which can be reduced if the municipality wishes to sell the excess energy produced back to the national energy supplier in the country.

Cost of the system for the battery-based solar PV system is R 649 883 554 ($ 42 995 649) and for the battery-based wind turbine system is R 57 538 299 664 ($ 380 667 671 2), these amounts are taken as the initial investment respectfully. Revenue collected in 2016 which is R 6 893 384 ($ 456 059.49) and revenue collected in 2017 which is R 7 437 498 ($ 492 057) is combined and taken as cash inflow per period.

$$\text{Payback period} = \frac{Initial\ Investment}{Cash\ inflow\ per\ period}$$

$$\text{Payback period (Solar PV)} = \frac{649\ 883\ 554}{6\ 893\ 384{,}83 + 7\ 437\ 498{,}1} = 45.3 \text{ years}$$

$$\text{Payback period (wind turbine)} = \frac{57\ 538\ 299\ 664}{14\ 330\ 882{,}93} = 4014.10 \text{ years}$$

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4. CONCLUSIONS

The main aim of this study was to investigate alternative power generation for local municipalities in order to enable more autonomy and that can help to reduce the pressure placed on the National Gird. To meet the load demand of 2038 houses in Koffiefontein a battery-based solar PV system of size 32 608 kW is required, or a battery-based wind turbine of size 346 460 kW is required. The initial cost of the battery-based solar PV system is R 649 883 554 ($ 42 995 649) while the initial cost of the battery-based wind turbine system is R 57 538 299 664 ($ 380 667 671 2).

The cost of energy for the PV system suggested for Koffiefontein houses is R 6.10/kWh ($ 0.40) with the yearly electricity production of 27 661 kWh. The wind turbine system has the cost of energy of R 776/kWh ($ 51.34) with the yearly electricity production of 1 907 kWh. The PV system has high excess electricity of 18 817 kW while the wind turbine system has an excess electricity of 326 kW.

After performing the payback calculations, the battery-based solar PV system indicated to be the best renewable energy system to be used in Koffiefontein. The cost of energy for the system is cost effective for municipal customers. The municipality will collect more revenue after paying off the system. The payback period maybe reduced if the municipality wishes to sell the excess energy produced back to the national energy supplier in the country.

The municipality should consider doing an energy audit at least every two years to make sure that they are aware of any energy loses so that it can be addressed before it affects revenue collection of the municipality. The municipality should consider installing battery-based solar PV systems for the businesses also so that they may have excess to electricity during load shedding and reduce the pressure on placed on the national grid during high energy demanding hours of businesses.

This study does not include hydro power systems, biomass and geothermal renewable energies. This research is only focused on the electricity sales of one municipality, it does not include electricity loses

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due to tampered meters. Renewable energy alternatives such as solar and wind are gaining momentum and will help in providing electricity to future new developments.

REFERENCES

Alfreds, D. (2018, October 29). *Revealed: Here's where the worst air pollution is in SA*. https://www.news2.com/amp/news24/green/news/revealed-heres-where-the-worst-air-pollution-is-in-sa-20181029

Belu, D. R. (2014). Teaching renewable energy system designs and analysis with Homer. In *121st ASEE Annual Conference and Exposition.* Indianapolis. https://www.asee.org/file.server/papers/attachment/file/0004/5010/ASEE-2014-Teaching_Renewable_Energy_System_Design_With_HOMER.pdf

Coetze, D., & Mart-Mari, E. (2016). The impact of load shedding on the construction industry in South Africa. In *9th cidb Postgraduate Conference*. Cape Town, South Africa. https://openbooks.uct.ac.za/uct/catalog/download/cidb/7/210-2?inline=1

Davidson, D. O. (2010). Recomendation to the World Bank Group on leading to South Africa for Eskom Investmentsupport project that include a large coal burning power station at Medupi. *External peer review report on Eskom,* 1-6. https://www.climateinvestmentfunds.org/sites/default/files/expternal%20peer%20review%20report%20on%20Eskom.pdf

Eskom. (2018, February 8). *Eskom holdings SOC ltd*. https://www.eskom.co.za

Garni, H. Z. (2017). Optimal design and analysis of grid-connected photovoltaic under different tracking systems using Homer. *Energy convertion and management, 155*(1), 1-57. https://dx.doi.org/10.1016/j.enconman.2017.10.090

Koko, S. (2014). Micro-hydrokinetic for remote rural electrification. *International journal of electrical, Robotics, Electronics and Communication Engineering, 8*(11), 1384-1388. https://doi.org/10.1016/j.epsr.2015.04.018

https://doi.org/10.17993/3ctecno/2021.v10n3e39.39-55

Nehrir, N. (2011). A review of hybrid Renewable/Alternative energy systems of Electric Power Generation Configuration,Control and Application. *IEEE Transactions on sustainable energy 2*(4), 393-399. http://dx.doi.org/10.1109/TSTE.2011.2157540

Niselow, T. (2019, March 24). *Fin24. Load shedding through the years and how Eskom has struggled to keep the lights on*. https://m.fin24.com

Palyi, A. (2015). The contribution of the state audit office to good governance and renewable of accounting. *Public Finance Quarterly, State audit office of Hungary, 60*(4), 1. https://www.asz.hu/storage/files/files/public-finance-quarterly-articles/2015/a_palyik_2015_4.pdf

Sen, R. (2013). Off-grid Electricity generation with renewable energy technology in India: An application of Homer. *Renewable energy, 62*(3), 1-15. http://dx.doi.org/10.1016/j.renene.2013.07.028

South African Government. (2011). *Local government budgets and expenditure review*. http://www.gov.za/2011-local-government-budgets-and-expenditure-review

Swart, A. J. (2018). Final pass rate fluctuations of power engineering students may be related to load shedding and not load shifting. *International Conference on Multidisciplinary Research, Mauritius.* https://www.researchgate.net/publication/326380796_Final_Pass_Rate_Fluctuations_of_Power_Engineering_Students_May_Be_Related_to_Load_Shedding_and_not_Load_Shifting

https://doi.org/10.17993/3ctecno/2021.v10n3e39.39-55

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OPTIMIZATION OF RECLOSER METHODS ON MEDIUM VOLTAGE DISTRIBUTION NETWORKS

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ABSTRACT

Reassessing methods within a business is important as it can prove certain concepts could indeed work, improve current methods and reinforces knowledge to the assessors. The utility's (Eskom) recloser placement methodology mainly focuses on improving their performance figures and reaching their performance targets and does not focus on the financial aspect of their methods. The purpose of this paper is to present a method that will optimize the placement of reclosers on medium voltage distribution networks. Eskom can by focusing on the financial aspects of the recloser placements, benefit by improving performance as well as saving money at the same time, especially during fault conditions. A cost-benefit analyses methodology is applied where data is derived from a medium voltage distribution network in the Free State that serves more than 2000 customers. The number of reclosers and the placement of them will be determined by using matrix tables and formulas. Data was extracted from the utility record systems. The findings suggested that a recloser can pay itself back within one year using this method. In order to make an informed decision as to the placing of a recloser on a medium voltage distribution network, it is recommended to use the proposed method. The proposed method will assist in the decision as to the viability of placing a recloser on a specific pole location. Future studies may be done by combining recloser placement methods with other protection sensing equipment like fault path indicators and current-voltage monitoring systems to isolate and find faults.

KEYWORDS

Recloser, Placement methodology, Medium voltage distribution networks.

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1. INTRODUCTION

"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it" (Harrington, n.d.). These words by H. James Harrington (n.d.) is true as it all starts by measuring.

Measurement can be defined as a process of empirical, objective assignment of symbols to attributes of objects and events of the real world, in such a way as to describe them. Strongly defined measurement is a measurement that conforms to the paradigm of the physical sciences (Finkelstein, 2003).

The South African utility company Eskom is currently in financial difficulties, thus looking into the financial importance of decision making is becoming more important. Reclosers on electrical networks are essential protection devices. Deciding on how many and where to place them on the networks makes all the difference (Thomas et al., 2019). The utilities current method to decide on the number and placement of reclosers, focusses on the network lengths and number of customers. The utility does not consider the financial importance when deciding on the number of reclosers and placements of them.

The importance of this process is to prove that a concept of other methodologies can indeed work. The purpose of this paper is to present a method that will optimize the placement of reclosers on medium voltage distribution networks. A cost-benefit analyses methodology is applied where data is derived from a medium voltage distribution network in Free State serving over 2000 customers. The paper firstly commences with a brief discussion of the concept "recloser" and placement thereof. In the setup section a flowchart was used to explain the setup, then the research site was discussed explaining in more detail the network used, then in the methodology section the method used was explained in more detail and that was followed by the results and the conclusions.

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2. METHODOLOGY

2.1. RECLOSER PLACEMENT METHODOLOGIES

When considering the placement of reclosers, the term recloser can be defined as an automatic circuit breaker that clears transient faults and isolates permanent faults and is placed on an overhead medium voltage distribution network (Tavrida Electric, n.d.). The reach or zone of a recloser is defined as a section of a power network that the recloser operates in , while protection devices outside the reach or zone will operate before the recloser (Azari, Chitsazan, & Niazazari, 2017). Before reclosers were available, overhead networks were protected by indoor circuit breakers at the source transformer and thus, the tripping of the breaker due to a fault affected many customers. A two-shot auto-reclosing scheme was introduced on source breakers in order to reduce the loss of supply, but the disadvantage was that a large number of customers were disconnected when a transient fault occurred. This lead to the development of special circuit breakers, which were the forerunners of the modern auto-reclosers of today (Ennis, Clarke, & Stewart, 1994).

Consider just the term “recloser placement“ a Google Scholar search for this term reveals some 3290 results. Performing a more advanced search reveals that 1420 results were found in the last five years alone, showing that studies are still being compiled, which indicates the importance of the topic in the electrical industry of today.

By optimizing the placement of reclosers on medium voltage distribution networks, the reliability and performance of networks can be improved as well as saving money at the same time, especially during fault conditions. This may be accomplished by using a cost-benefit analyses methodology, as outlined in the next section.

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2.2. SETUP

Figure 1 indicates the methodology that was followed in this study using a flowchart. Meters placed at the substations were used to determine the power usage from a specific electrical network (Pichugin, Soldatov, & Pinaev, 2019). The metering unit placed at the substation measures the total load for a specific network. Using this information the average load can be determined over a certain period (Soluyanov, Fedotov, & Ahmetshin, 2019). The systems Eskom uses has data of all the installed transformers as well as the type of customers. Using this information, the total installed capacity of the network can be determined as well as the type of customers on the network.

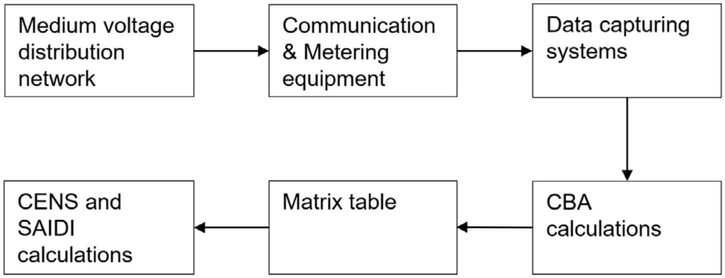

Figure 1. Flowchart of recloser placement system.

Source: own elaboration.

Furthermore, the type of tariff of each customer can be determined and necessary calculations can be done in order for the cost-benefit analyses (CBA) methodology to be more accurate. With the calculations completed the number of reclosers can be determined and placed using the matrix table.

2.3. RESEARCH SITE AND METHODOLOGY

For this paper, one network will be investigated using a CBA methodology for placing of reclosers. For the purpose of this case study, an 11 kV overhead line medium voltage distribution network was selected,

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as shown in Figure 2. Data for the case study was extracted from Eskom's Network and Equipment Performance System (NEPS) for the years 2014-2017.

This network had a total line length of 238 km, a total customer base of 2188 with eight reclosers installed. A total of 1895 customers were pre-paid customers, 267 were small power users, and 26 were large power users. Small and large power users are determined based on their tariff, but usually, the small power users transformer size ranges between 25-200 kVA, where the large power user ranges between 50-500 kVA. The total installed capacity on this network was 30046 kVA, and by the last data measured in 2017 an average of 2924.95 kVA load was measured.

Figure 2. Geographical layout of the 11 kV overhead line medium voltage distribution network.

Source: own elaboration.

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A CBA methodology can be used for many purposes, as in this case, it will be used to implement recloser placement on a network. The CBA will be used to give justification and reasoning on why a recloser will be placed at a specific location on the network. It takes into consideration all the costs involved in installing a recloser at a specific location and the benefits thereof. The CBA will indicate whether it will be financially beneficial to the business to install reclosers at specific locations on a specific network. Not only will it indicate the financial benefits but it will also improve the performance targets on the networks as more customers will be isolated during fault conditions.

Cost of energy not served (CENS) can most easily be explained as the loss of income for Eskom during an interruption, as customers will be without electricity/power. CENS will be based on the load profile of the network or section thereof and the associated tariffs of the connected customers. The load provided by Eskom to the network is not always used fully as the energy consumed by customers will also change during the day and during different seasons. To calculate an average of the load consumed, a load factor (LF) will be used. To determine the power (kVA) hours lost, a traced calculation is done for each interruption of the affected customer's transformers. A CBA is a systematic evaluation on economic advantages and disadvantages of a set of investment alternatives, it is often a useful yardstick for measuring efficiency (Paramasevam, Hassan, & Mohamed, 2001).

Typically a "base case" is compared to one or more alternatives. A cost benefit analysis will give the answer to, financially what advantages an alternative method will provide. The objective of cost benefit analyses is to translate the effects of investment into monetary terms as benefits only incur over long periods of time while capital costs incur that initial year. Costing elements can include, on-going maintenance costs, travelling costs, remaining capital value etc. After the project has been executed operating costs may increase due to longer travelling distances, but travelling times may decrease reducing costs again.

To determine the "Net costs" all costs involved in installing and commissioning of a recloser is calculated. To determine the "Nett benefits" the CENS will have to be calculated using Eskom's tariffs. After the CBA is determined, the maximum number of recloser installations will be known. After which, the

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reclosers have to be placed where the CBA calculations will equal more than one. Because of the layout of the customers, the maximum number of recloser placements might not be possible as calculated. The settings of the protection gradings play an important role (Thomas, Van Zyl, & Groenewald, 2017).

After the real number of reclosers placements and their positions are realized, they must be categorized according to importance to the network, from the most important recloser placement to the least important recloser placement.

A payback period can also be calculated. The Payback Period (PS) is calculated by dividing the cost of the project with the savings to be made per year (Wong, Eames, & Perera, 2007). This will determine the period it will take to recover the cost of the initial investment. For this methodology, a one year payback period is used. Apart from installing the number of reclosers on the networks as per the calculations used, the benefits have to be substantial.

Using the calculations and finding the CBA to be more than one, there are other considerations to be taken, for instance, the number of reclosers placed in series shall be limited to four due to protection grading constraints (Kleynhans & Gütschow, 2015). Other determining factors will be fault history, telecommunication in the area, geographical obstacles, etc. These all play a vital role in the placement of reclosers. For the optimum placement of reclosers, it is imperative that we consider and compare the different parameters. For this a matrix table was created.

The criteria for the matrix include:

- Communication: if the communication signal strengths are below the minimum target, then an alternative location will have to be selected for the recloser installation.
- Failure rates on tee-offs: number of faults in the last three years.
- Geographical obstacles: roads can have an effect on how accessible the terrain is for example crossing of rivers and mountains or rough terrain.

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- Poor performing lines – Pareto networks that have underperformed in the last 5 years.
- Sensitive customer's for instance a bakery, mine, dairy farmer, etc.
- High total line length – If the line is long and it takes time to get to fault.
- High lightning density or know pollution – If the area is known for its lightning strikes it would probably be recommended to place recloser elsewhere.

The matrix table was established by sending questionnaires to the relevant departments within Eskom in the Free State, and from the feedback, the matrix table and each categories importance were taken into consideration and created.

After the optimum placements of reclosers are determined, the key performance indicators (KPI's) can be calculated to show the improvement the networks would have had using the actual history fault data.

KPI's measured are the system average interruption index (SAIDI), system average frequency index (SAIFI) and momentary interruption frequency index(MAIFI).

The SAIDI shows the average duration of a sustained interruption the customer would experience per annum. It is usually measured in customer minutes or hours of interruption. The SAIDI is the KPI that Eskom focusses on as it is used to determine the performance of the utility by the National regulato of South Africa (NERSA).

3. RESULTS

The results indicate that by using the CBA methodology on the network (Jacobsdal Rural - Pramberg), a total of 22 reclosers can be installed that will have a 1>CBA and will thus pay itself back within one year. The rankings of reclosers to be placed in case of budget constraints can be seen in Table 1 below. This indicates the installation sequence of the reclosers from ranking one up until twenty-two.

Table 1. Network recloser pole number rankings.

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Ranking	Matrix Pole numbers	Ranking 2016-2017	Ranking 2015-2016	Ranking 2014-2015	Rankings overall
1	POLE387	2.24	2.5	2.68	2.47
2	POLE183	2.53	2.53	2.16	2.41
3	POLE61	2.13	2.13	2.82	2.36
4	POLE266	2.42	2.24	2.27	2.31
5	POLE181-47	2.5	1.72	2.23	2.15
6	POLE15-2	1.88	1.44	1.95	1.76
7	POLE84-32-1	1.75	1.31	1.96	1.67
8	POLE84-86-31	1.89	1.63	1.33	1.62
9	POLE84-1	1.6	1.34	1.89	1.61
10	POLE84-51-1	1.74	1.22	1.48	1.48
11	POLE84-53-1	1.67	1.41	1.22	1.43
12	POLE84-53-46	1.22	1.22	1.85	1.43
13	POLE15-15	1.36	1.36	1.54	1.42
14	POLE15-18-24	1.14	1.22	1.8	1.39
15	POLE84-85	1.41	1.41	1.33	1.38
16	POLE15-18-1	1.36	1.18	1.54	1.36
17	POLE60-1	1.44	1	1.36	1.27
18	POLE0-16	1.51	1.07	1.1	1.23
19	POLE60-13-1	0.92	1.26	1.36	1.18
20	POLE84-76-1	1.22	1.22	1.03	1.16
21	POLE60-12-1	0.92	1	1.36	1.09
22	POLE15-44	0.74	0.74	1.14	0.87

Source: own elaboration.

The ranking changes from year to year, as can be seen in Table 1. As every year, the data used in the criteria will be changed, but using a three year period should give a good indication of the best order of ranking when placing the reclosers.

Figure 3 gives a more visual example of where these reclosers will be placed on the network.

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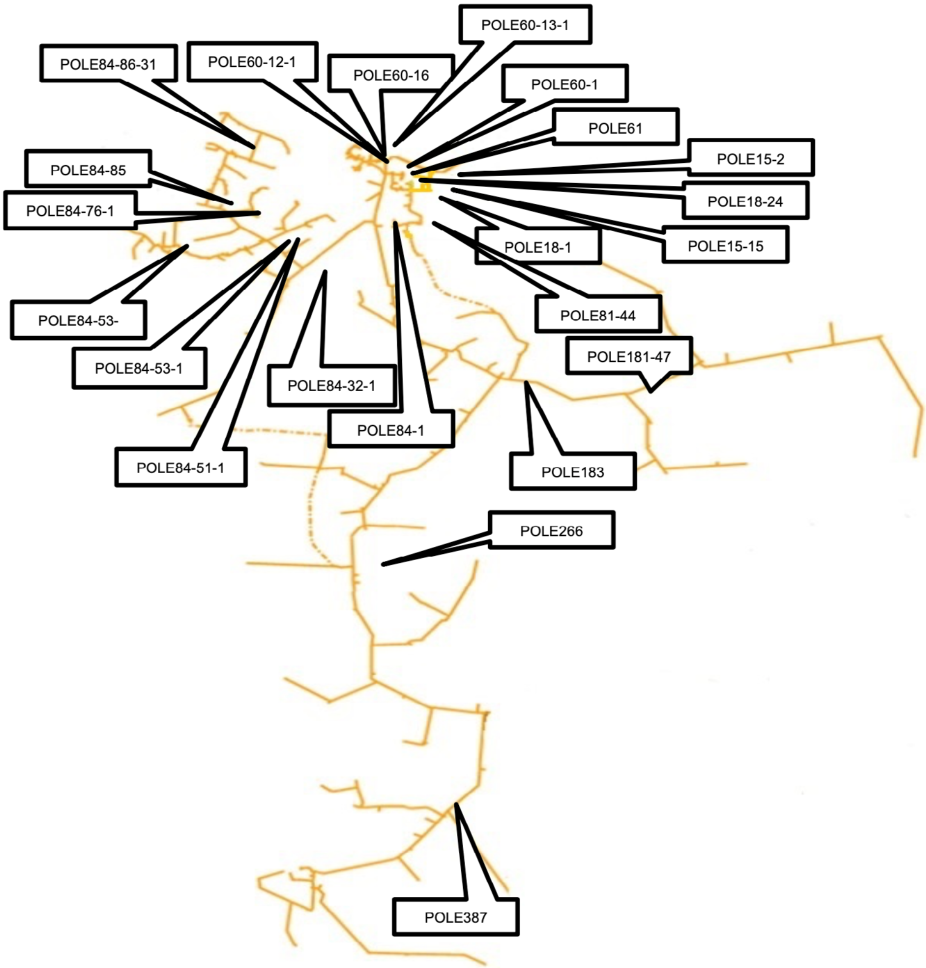

Figure 3. Geographical 11 kV medium voltage distribution network layout.

Source: own elaboration.

Actual savings from optimizing the recloser placements using a CBA methodology resulted in an average of 24.51% from a financial aspect and 24.42% from a performance aspect over a three year period as can be seen in Figure 4.

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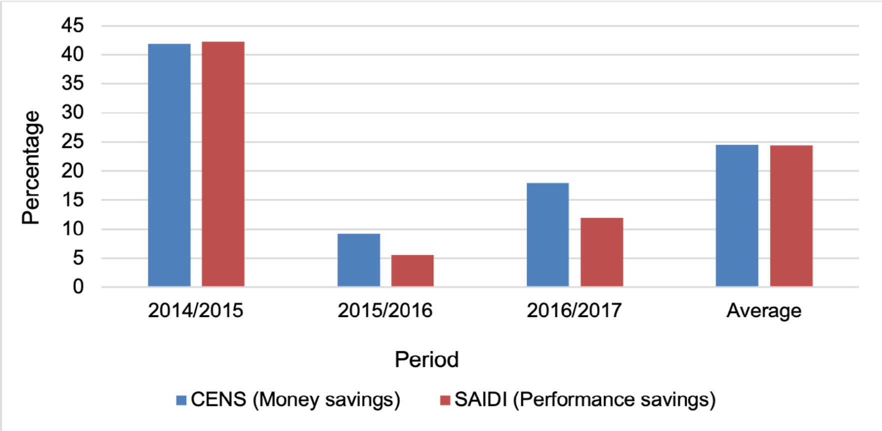

Figure 4. Fiancial and performance improvements.

Source: own elaboration.

The results in Figure 4 is the financial and performance savings that could have been improved on, based on the fault history of the chosen network. It can be seen that for the year 2015/2016 fewer faults occurred, thus fewer improvements were found, but for the year 2014/2015 there were more faults and thus more improvement were found.

4. CONCLUSIONS

The purpose of this paper saw to present a method that will optimize the placement of reclosers on medium voltage distribution networks. The business will benefit by using this method for recloser placements on their distribution networks by improving the performance targets. The method indicates that the utility should not focus on lowering the numbers but focus on the type of customers (Pre-paid users, Small power users, Large power users) as they play a significant role in the CBA calculations. The CBA assessment and payback period will give a clear indication of the financial viability in reclosers placements using a design to cost methodology. This can be seen with the results in this paper indicating a

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24.51% financial saving and a 24.42% increase in performance over a three year period. The limitations were that the loads cannot be measured on the tee-offs or each transformer of the network and can only be measured at the substation. In addition, the data used for fault history is a manual procedure typed by employees closing the works orders, who does not always give all the necessary feedback of the fault found. Eskom can use these results to change or possibly optimize their recloser placement standards and strategies to benefit the company. Implementation of these results may lead to financial savings as well as improvement in reliability and performance of medium voltage distribution networks.

REFERENCES

Azari, R. N., Chitsazan, M. A., & Niazazari, I. (2017). Optimal recloser setting, considering reliability and power quality in distribution networks. *American Journal of Electrical Power and Energy Systems, 6,* 1–6. http://www.sciencepublishinggroup.com/journal/paperinfo?journalid=165&doi=10.11648/j.epes.20170601.11

Ennis, C., Clarke, R., & Stewart, J. S. (1994). Automation of overhead line distribution systems. In *1994 Fourth International Conference on Trends in Distribution Switchgear,* London, UK, pp. 90–94. https://ieeexplore.ieee.org/document/341496/

Finkelstein, L. (2003). *Fundamental of Measurement*.

Harrington, H. J. (n.d.). Goodreads. https://www.goodreads.com/quotes/632992-measurement-is-the-first-step-that-leads-to-control-and

Kleynhans, T., & Gütschow, D. (2015). *Planning standard for distribution network reliability.*

Paramasevam, G., Hassan, M. N., & Mohamed, N. (2001). Cost benefit analysis for implementation of environmental management systems. *Proceedings Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing*. https://doir.org/10.1109/ECODIM.2001.992464

Pichugin, V. N., Soldatov, A., & Pinaev, A. M. (2019). Spectral approach to the estimation of the time series of the power change in the substation metering units and its application in the control modes of substation electricity metering systems. In *IOP Conference Series: Materials Science and Engineering, Volume 663, International Conference on Extraction, Transport, Storage and Processing of Hydrocarbons and Minerals* 19-20 August 2019, Tyumen, Russian Federation. https://www.semanticscholar.org/paper/Spectral-approach-to-the-estimation-of-the-time-of-Pichugin-Soldatov/def2ec446c353fdbf513e0e461033982d89e1218

Soluyanov, A. R., Fedotov, Y.I., & Ahmetshin, A. R. (2019). Calculation of electrical loads of residential and public buildings based on actual data. In *IOP Conference Series: Materials Science and Engineering, Volume 643, International Scientific Electric Power Conference* 23–24 May 2019, Saint Petersburg, Russian Federation. https://iopscience.iop.org/article/10.1088/1757-899X/643/1/012051

Tavrida Electric. (n.d.). *Tavrida Electric Automatic Circuit Reclosers*. https://www.tavrida.com/tena/solutions/automatic-circuit-reclosers-15-27-kv/

Thomas, R., Van Zyl, S., & Groenewald, P. (2017). *Protection settings philosophy for MV distribution networks.*

Thomas, R., Van Zyl, S., Naidoo, R.M., Bansal, R.C., Mbungu, N.T., & Bipath, M. (2019). Recloser based energy exposure assessment of a distribution network. *Journal of Energy in Southern Africa, 30*(4), 41–50. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2019000400004

Wong, I. L., Eames, P. C., & Perera, R. S. (2007). A review of transparent insulation systems and the evaluation of payback period for building applications. *Solar Energy, 81*(9), 1058–1071. https://doi.org/10.1016/j.solener.2007.04.004

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QUALITATIVE STUDY OF AIRFLOW STRUCTURE ACROSS WOODEN LOUVRED WINDOW PANELS FOR NATURAL VENTILATION APPLICATIONS

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ABSTRACT

Window ventilation usually used in energy-efficient buildings as an effective natural ventilation system to provide an adequate opening for fresh air to flow into the interior space. It could help to reduce the indoor air temperature and limit the contaminants in buildings. This study aimed to visualise the airflow structure across a wooden louvred window panel using the smoke flow visualisation technique at different airflow speeds of 0.5, 1.0, 2.0, 3.0 and 5.0 m/s in a closed-loop wind tunnel. Two Sony 1920 × 1080i cameras captured the airflow structure, which took the side view, rear view, front view and back view images. The wooden louvred window panel promotes optimum outdoor airflow and facilitates continuous air exchange to replace the indoor air. Results showed that smoke filled the space quickly at the highest airflow speed of 5 m/s. This study used an inclination angle of 75° for the wooden louvred window panel to avoid rain splatter. Besides, wood material could be used as a façade shading device. Therefore, installing the wooden louvred window panels could enhance natural ventilation, ensure indoor thermal comfort and reduce indoor air contaminants.

KEYWORDS

Passive Design, Natural Ventilation, Airflow Structure, Indoor Air Quality, Thermal Comfort, Sustainable Development.

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1. INTRODUCTION

Malaysia is a tropical country that experiences a hot and humid climate throughout the year. It is near the equator, whereas approximately one-third of the world population experiences hot–dry or warm and humid climates (Jamaludin *et al.*, 2015; Laurini *et al.*, 2017). High humidity and temperature levels increase the risk of thermal discomfort and moisture problems in indoor settings (Hamimah *et al.*, 2010). A study by Jamaludin *et al.* (2015) found that the indoor air temperatures of a residential building in Malaysia at different microclimates exceed the acceptable limit of thermal comfort suggested in the Malaysian Standard (MS 1525:2007) (23 °C–26 °C), with the highest indoor temperature being 32.6 °C under the Kuala Lumpur climate.

In response to the effects of high indoor thermal conditions, people install air-conditioning systems in their indoor environment for cooling purposes (Jamaludin *et al.*, 2015). The practice may increase the energy demand and energy cost of residential and commercial buildings and thereby challenge the sustainable cities' effort (Jamaludin *et al.*, 2015; Kubota & Toe, 2015; Kassim *et al.*, 2016; Cui *et al.*, 2017; Laurini *et al.*, 2017). Modern technology recirculates the indoor air instead of refreshing it, contributing to poor indoor air quality (Spiru & Simona, 2017). Moreover, air conditioning usage adds to the imperfect removal of indoor air contaminants (Cui *et al.*, 2017), including carbon monoxide, carbon dioxide, formaldehyde and biological contaminants (Kaunelien *et al.*, 2016; Li *et al.*, 2017; Cheung & Jim, 2019). Indoor air quality needs to be maintained within acceptable limits as it can affect human health (Sun *et al.*, 2015; de Robles & Kramer, 2017; Steinemann *et al.*, 2017; Amoatey *et al.*, 2018; Krawczyk & Wadolowska, 2018).

As a solution to this problem, the wind from outside can be used as natural ventilation to eliminate the need for air-conditioning systems. A natural ventilation system is a passive design strategy for buildings, applied for cost-effective electricity consumption and fossil fuel usage (Allocca *et al.,* 2003; Gratia & De Herde, 2007; Ahmed & Wongpanyathaworn, 2012; Zhong *et al.* 2012; Aflaki *et al.*, 2014). The adoption of such systems is aimed at achieving sustainable development goals and is ideal as they do not incur

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any energy cost (Kassim *et al.*, 2016). Fresh air is fundamentally required in the interior spaces to provide enough oxygen for breathing, reduce excessive heat, limit indoor air contaminants, decrease CO_2 concentrations and dilute and remove odours (Bayoumi, 2017).

In natural ventilation, fresh outside air is induced naturally by the temperature and pressure differences between spaces to replace the indoor air continuously through openings (vents, windows, doors and so forth) (Bangalee *et al.*, 2014). Natural ventilation can either be wind-driven natural ventilation (cross ventilation) or buoyancy-driven natural ventilation (stack ventilation); the former attributed to pressure differences generated by the wind while the latter is caused by buoyancy forces (Mohammadmirzaei, 2018). Cross and stack ventilation may also co-occur, in which wind and stack effects could reinforce or oppose one another (Allocca *et al.*, 2003). Figure 1 illustrates the cross and stack ventilation in a building. Cross ventilation supplies and extracts the air flowing in the same building level that passes through vertical openings, whereas stack ventilation concerns the upper and lower openings (Ohba & Lun, 2011).

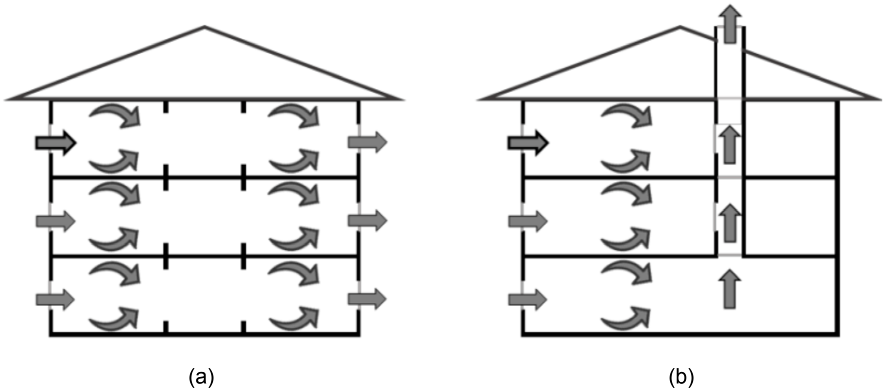

Figure 1. (a) Cross ventilation and (b) stack ventilation.

Source: (Ohba & Lun, 2011).

Besides, the opening location can enhance the effectiveness of natural ventilation through cross ventilation. For single-sided walls, leeward walls are better opening locations than the windward walls (Ma *et al.*, 2017). Extensive recirculation is produced at the centre of the building with single-sided walls.

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The direction of airflow in windward ventilation is anticlockwise as opposed to leeward ventilation, and it is more robust due to the vortices behind the buildings. Kassim *et al.* (2016) reported that the best opening location is at the upper part of the windward façade as it allows a large amount of air to penetrate a building; however, the ventilation rate decreases as the opening position shifts towards the lower part of the building façade.

The current study is conducted to develop and improve the previous research by Rasli *et al.* (2019) by applying a wooden louvred window panel to enhance the outdoor air inflow. In that study, Rasli *et al.* (2019) visualised the airflow structure of outdoor air that permeates through the window panels with apertures using the smoke flow visualisation technique in a wind tunnel laboratory. The results suggested that double apertures with a 2.4% opening on window panels could promote optimum outdoor airflow indoors relative to single apertures (1.2%) and no aperture (0%). Double apertures also provide security by which windows be kept closed for 24 h.

Hence, this wind tunnel study's objective is to visualise the airflow structure across the wooden louvred window panel using the smoke generator technique at different airflow speeds of 0.5, 1.0, 2.0, 3.0 and 5.0 m/s. The proposed wooden louvred window panel can also provide protection from the rain splatter while allowing the air outside to come inside. Besides, wood material could be used as a façade shading system, in which due to its hygroscopic properties, it could be advantageous for occupants as it could lead to decreasing in energy cost, enhance energy efficiency and improve indoor comfort in buildings (Vailati *et al.*, 2018; El-Dabaa *et al.*, 2020). When wood is applied, it gives a passive motion technique stimulated by the variation of relative humidity which can be ideal in a tropical climate.

1.1. LOUVRED WINDOWS

Generally, louvres are apertures with angled slots either horizontally or vertically that permit air and light to pass through but at the same time block direct sunlight, rain and noise from penetrating the interior areas. Accordingly, a louvred window consists of integrated angled slats within a frame to perform such

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functions. For this study, a louvred window with horizontal slats was used. The effectiveness of airflow permeating through a louvred window is controlled by the input, geometry and output variables, as shown in Figure 2.

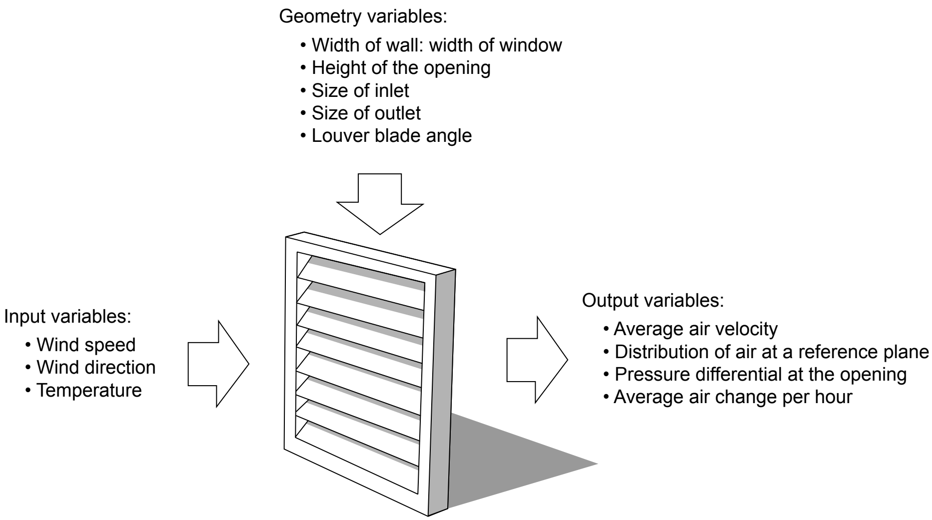

Figure 2. Variables that affect the airflow through a louvred window.

Source: (Chandrashekaran, 2010).

1.2. WIND TUNNEL

The experiment of smoke flow visualisation can be performed to visualise the airflow structure in and around the test model by using the illumination of smoke filaments in the test section of a wind tunnel. The use of wind tunnel experiment on the natural ventilation study was adopted in several works (Ohba *et al.*, 2001; Karava *et al.*, 2007; Chu *et al.* 2009; Chu *et al.* 2010; Ji *et al.*, 2011), while Elmualim (2006), Montazeri & Azizian (2009), Chandrashekaran (2010) and Esfeh *et al.* (2012) have included the smoke visualisation test in their natural ventilation studies using wind tunnels.

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The airflow in a wind tunnel has three different characteristics depending on the condition: laminar flow (i.e. streamline flow), transitional flow (i.e. between laminar and turbulent flow) and turbulent flow (i.e. chaotic flow) (Chandrashekaran, 2010). In laminar flow, the air moves in parallel at low velocities caused by the viscous air forces. In transitional flow, some of the air moves in parallel whilst some disperses. In turbulent flow, air moves at high velocities, and pressure varies irregularly in time and position. The Reynolds number (Re) characterises the airflow characteristics, in which the airflow may be laminar, transitional or turbulent when the Re is below 2,000, between 2,000 and 4,000 and more than 4,000, respectively (Figure 3).

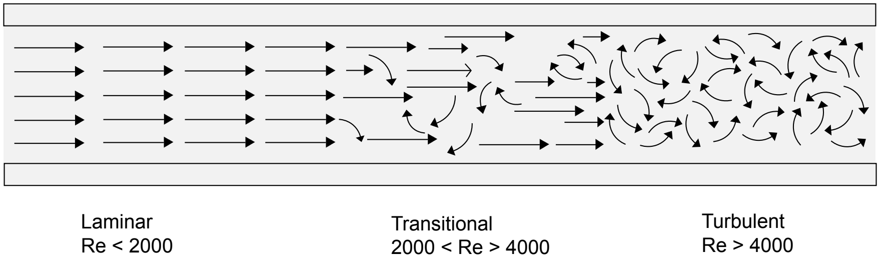

Figure 3. Characteristics of laminar, transitional and turbulent airflow.

Source: (Chandrashekaran, 2010).

2. MATERIALS AND METHODS

The ventilation openings of louvred windows from vernacular architecture techniques could improve cross-ventilation by increasing the indoor air pressure. They promote the outdoor airflow towards indoors to lower indoor air temperature and reduce indoor air contaminants. The variables used in this study for the model testing are the airflow speeds (i.e. 0.5, 1.0, 2.0, 3.0 and 5.0 m/s). The resulting airflow characteristics are subsequently analysed.

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2.1. DIMENSIONS OF WOODEN LOUVRED WINDOW PANEL MODEL

The louvred window used in this work was made of wood and had a smooth finish. The dimension of the slotted-up wooden louvred window panel was 36 cm (width) × 57 cm (height), inserted at the centre of a clear acrylic measuring 90 cm (width) × 60 cm (height), which served as the window base. A wooden frame holder measuring 100 cm (width) × 80 cm (height) was used to hold the wooden louvred window panel in a vertical position in the middle of the test section (Figure 4).

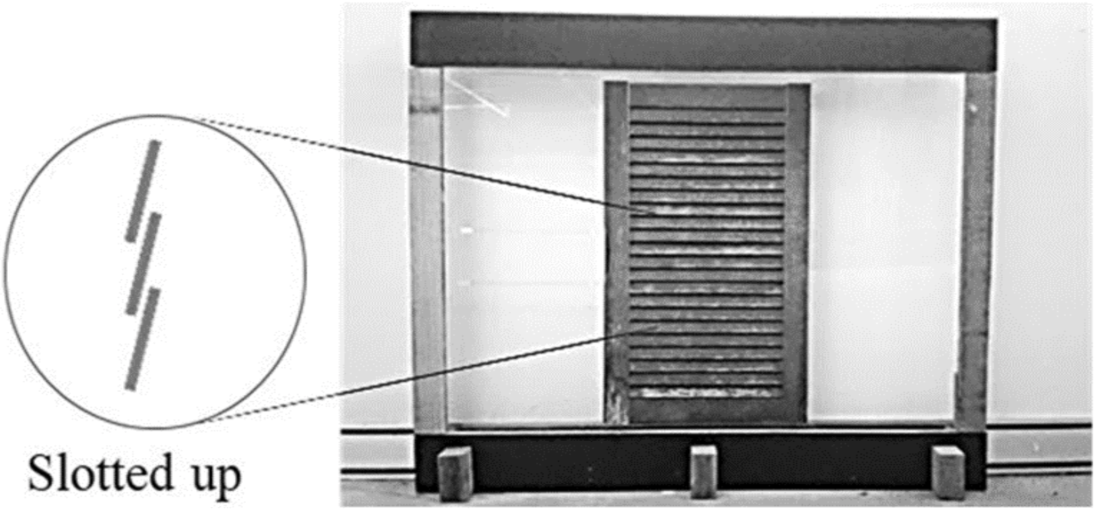

Figure 4. Configuration of the wooden louvred window panel.

Source: own elaboration.

2.2. THE ANGLE OF THE WOODEN LOUVRED WINDOW PANEL MODEL

Studies on the relationship between the louvre angles and natural ventilation performance were conducted by various researchers (Yakubu & Sharples, 1991; Hughes & Ghani, 2010; Chandrashekaran, 2010; Lee *et al.*, 2016). This study focused on a wooden louvred window panel model with 22 slots inclined at 75°,

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in which the gap between each slot was 2 cm (Figure 5). The free area's opening between the slots had a vital function as it influenced the velocity and pressure differences across the wooden louvred window.

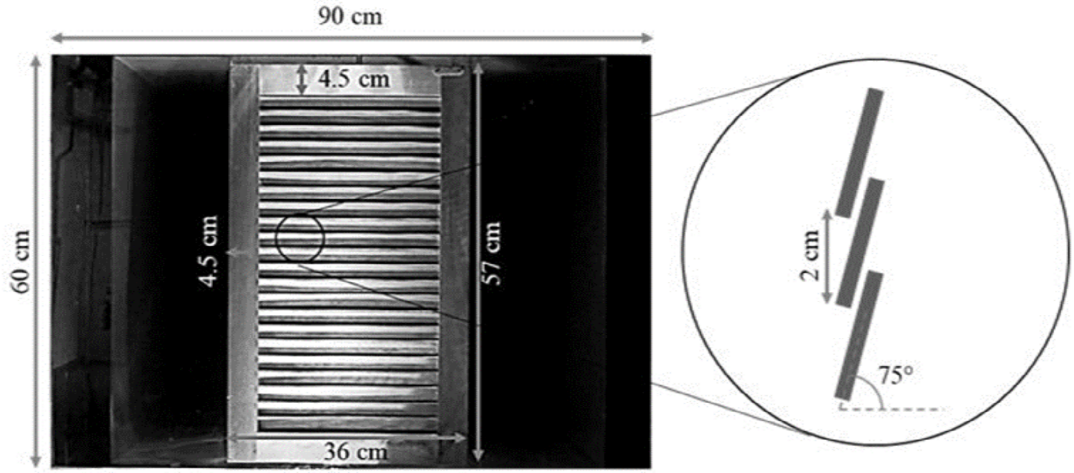

Figure 5. Dimension of the wooden louvred window panel with the slot's gap size and angle.

Source: own elaboration.

2.3. CLOSED-CIRCUIT WIND TUNNEL

The smoke flow visualisation testing was carried out at the Wind Tunnel Laboratory, Science and Engineering Research Centre, Universiti Sains Malaysia. The closed-loop wind tunnel measuring 2,052.6 cm (length) × 818.8 cm (width) × 350.0 cm (height) produces an airstream for the study of the effects of airflow moving in and around the wooden louvred window panel model. The model was then placed in the test section between the settling chamber and the wind tunnel diffuser. The wind tunnel had a rectangular test section measuring 1 m (width) × 0.80 m (height) × 1.80 m (length), a contraction ratio of 10:1 and a turbulence level of 0.1% for the flow speed of up to 80 m/s. The axial fan, with the aid of the diffuser downstream in the test section, drove the airflow to the test section. The airflow speeds were controlled using the wind tunnel's control panel and were verified using a hot wire anemometer.

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2.4. SMOKE FLOW VISUALISATION TECHNIQUE

The testing for smoke flow visualisation was conducted using the smoke generator technique to evaluate the airflow structure of the wooden louvred window panel model at different airflow speeds as illustrated in Figure 6. The wooden louvred window panel was placed at the centre of the wind tunnel test section while the smoke sources (smoke generator) were positioned vertically at 25 cm from the wooden window panel's midsection. The optimal distance contributed significantly to the best-illustrated streamlines of the smoke, which represented the airflow structure. The smoke generator was at the top of the wind tunnel test section while the smoke rake was positioned inside the test section.

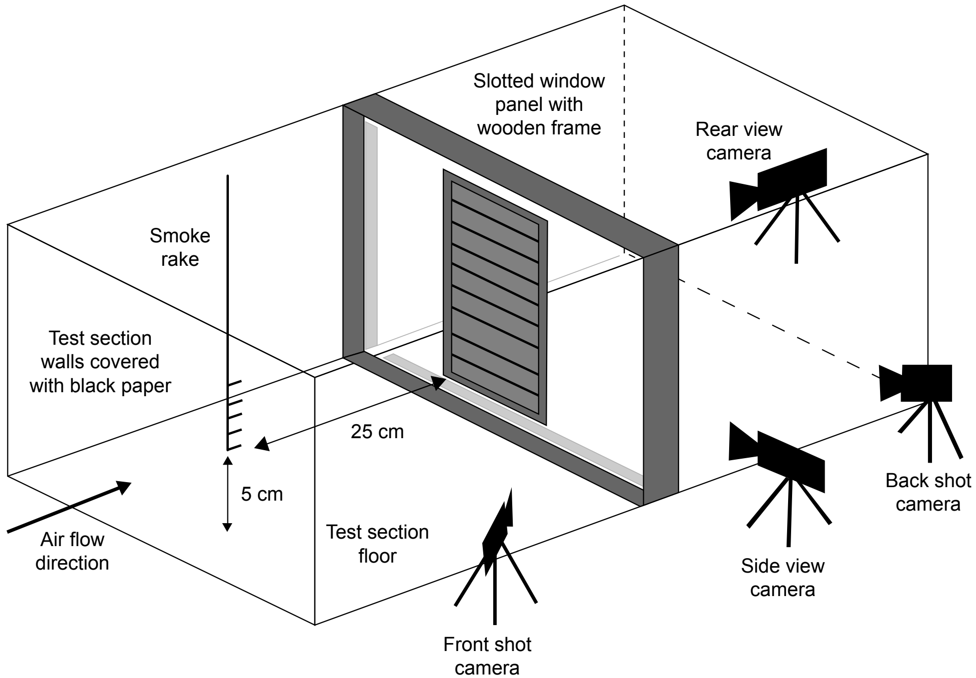

Figure 6. Illustration of wooden louvred window panel using the smoke generator technique at five different airflow speeds of 0.5, 1.0, 2.0, 3.0 and 5.0 m/s and different camera positions (i.e. side view, rear view, front view and back view) inside the wind tunnel test section.

Source: own elaboration.

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In the smoke generator flow visualisation technique, a smoke generator (SAFEX Fog Generator FOG 2010 by Dantec Dynamics) produces smoke particles at a rate of approximately 600 m^3/min. The smoke intensity was controlled using a handheld remote control with a rotary knob scaled at number 5 for a favourable amount (600 m^3) of smoke. The setup of the smoke generator is shown in Figure 7. The generated smoke particles were pumped through the smoke rake located at the inlet of the test section. Meanwhile, a flexible delivery tube was used to connect the smoke generator to the smoke rake.

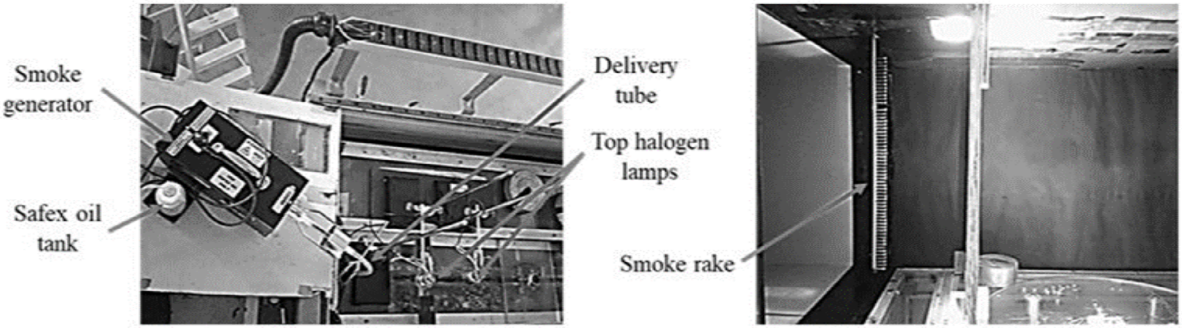

Figure 7. Flow visualisation setup using the smoke generator technique on the top and inside the wind tunnel test section.

Source: own elaboration.

Two Sony 1920 × 1080i cameras were mounted outside at the centre (side view) and inside (rear view) of the test section to record the airflow structure. The testing was repeated with both cameras mounted outside and positioned at the front and backside to capture these areas' flow structure. The test section's inner wall was installed with a black paper cover to minimise any reflection that could affect the results and to increase the clarity of the streamlines. Two white halogen light bulbs installed on top and at the bottom of the test section illuminated the smoke flow structure released from the smoke rake.

3. RESULTS

The wooden louvred window panel introduced in this study was aimed at promoting the optimum flow of fresh outdoor air into indoor spaces for passive ventilation and enhancing natural ventilation towards

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the development of sustainable buildings. Improved indoor air quality and thermal discomfort can be achieved (i.e. decrease the space's temperature) by increasing the natural ventilation area (Noman *et al.*, 2016; Lei *et al.*, 2017). Thus, the objective is to solve thermal comfort issues and improve air quality in indoor spaces (Ocak *et al.*, 2012; Hameed & Habeeballah 2013; Alananbeh 2017; Yu *et al.*, 2017; Nahar & Mahyudin 2018; Rasli *et al.*, 2019; Azuma *et al.*, 2020).

The side view, rear view, front view and back view images obtained in the wind tunnel testing are shown in Figures 8–12. Specifically, the figures show the airflow structure across the wooden louvred window panel based on the smoke generator technique at five different airflow speeds. The smoke streamlines from the smoke generator in the wind tunnel represented the outdoor airflow structure toward the indoor space.

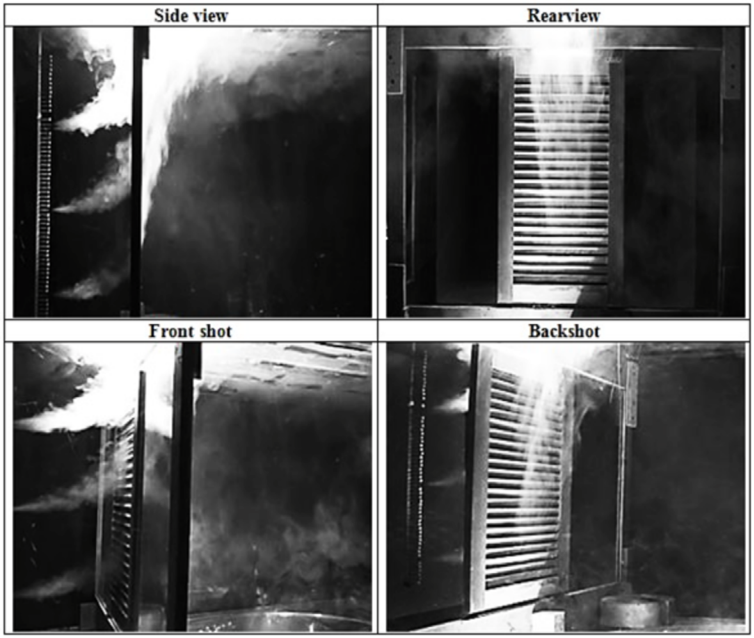

Figure 8. Visualised airflow structure across the tested wooden louvred window panel using the smoke generator technique at 0.5 m/s inside the wind tunnel test section.

Source: own elaboration.

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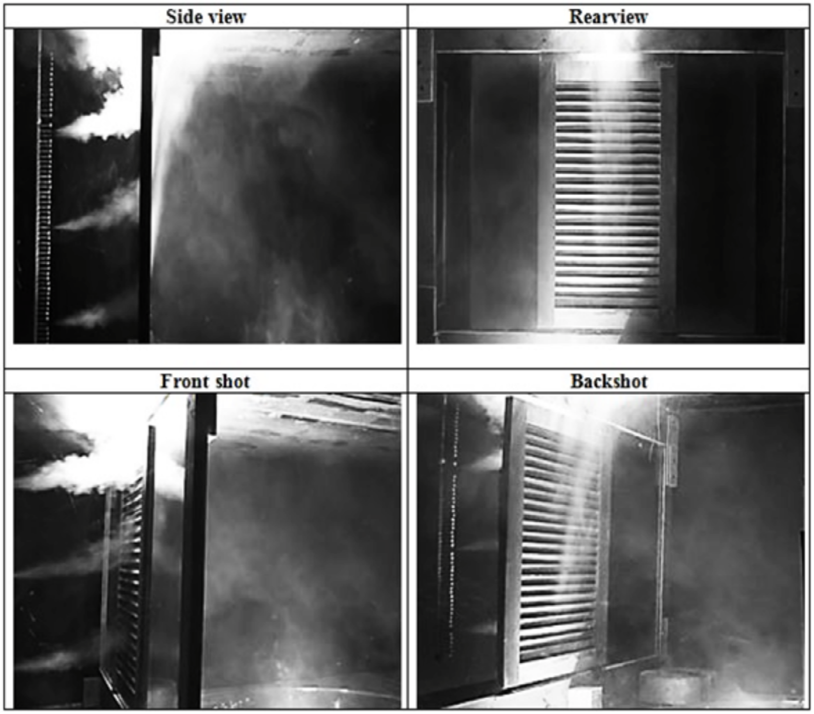

Figure 9. Visualised airflow structure across the tested wooden louvred window panel using the smoke generator technique at 1.0 m/s inside the wind tunnel test section.

Source: own elaboration.

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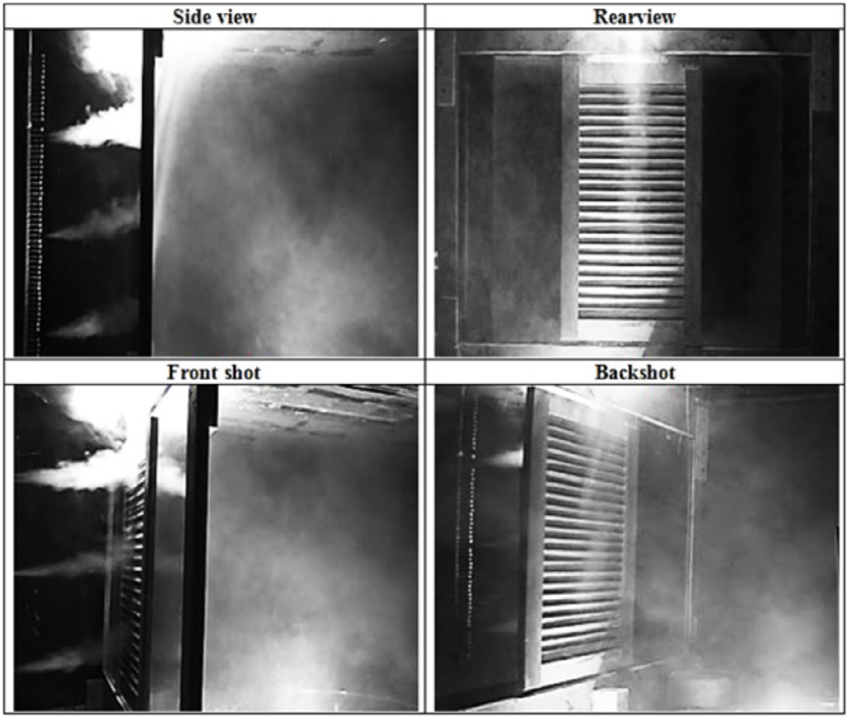

Figure 10. Visualised airflow structure across the tested wooden louvred window panel using the smoke generator technique at 2.0 m/s inside the wind tunnel test section.

Source: own elaboration.

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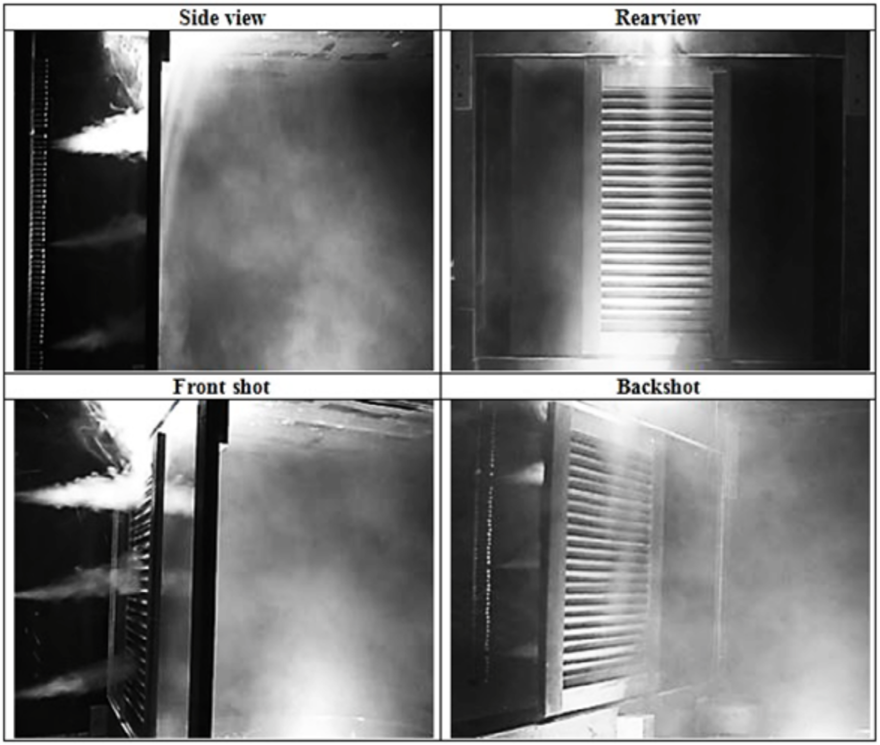

Figure 11. Visualised airflow structure across the tested wooden louvred window panel using the smoke generator technique at 3.0 m/s inside the wind tunnel test section.

Source: own elaboration.

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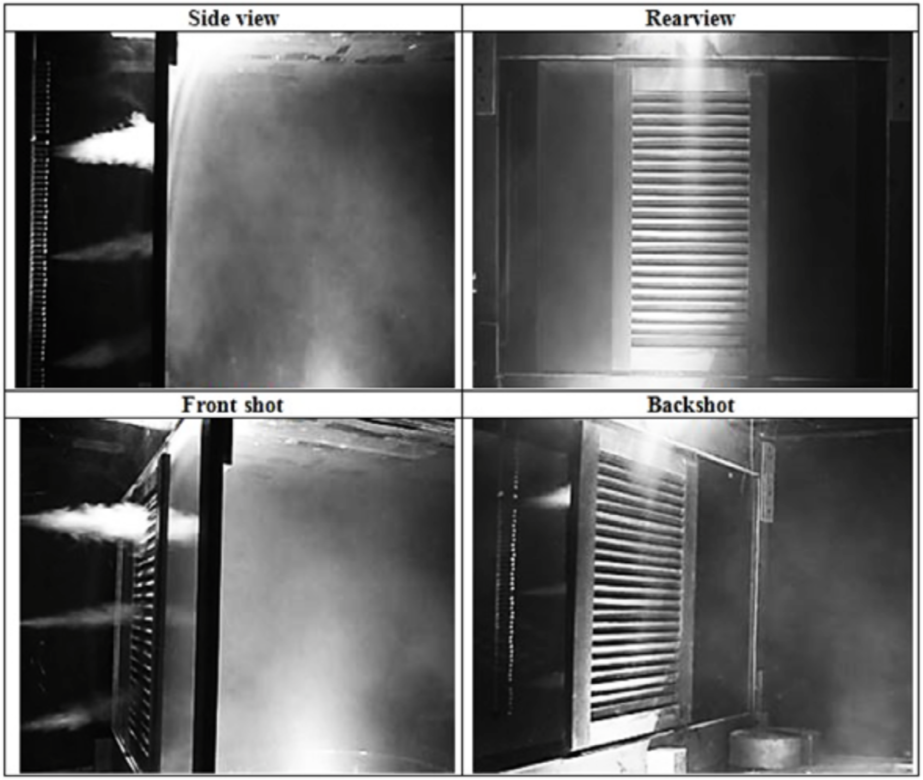

Figure 12. Visualised airflow structure across the tested wooden louvred window panel using the smoke generator technique at 5.0 m/s inside the wind tunnel test section.

Source: own elaboration.

In Figure 8, at 0.5 m/s, the airflow had quite a sharp upward curve pattern; it reached the louvres, then continued to concentrate towards the upper part of the space as it passed through the louvres, upon which the airflow spread slowly to the other amount of the space. A similar pattern could be seen for the speed of airflow at 1.0 m/s in Figure 9. However, less upward curve pattern of airflow was observed between the smoke rake and the wooden louvred window panel, and the airflow seemed to be spread faster to the other part of the space. At 2.0 m/s (Figure 10), a much lesser upward curve of airflow could

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be noticed before it entered the space and most of the airflow seemed to spread to the other part of the space as little concentration of airflow to the upper part of the space could be observed. Figure 11 shows that at 3.0 m/s, there was still some airflow that moves upwards after crossing the louvres even though simultaneously the airflow spread to the other part of the space. At 5.0 m/s, as shown in Figure 12, the upward movement of airflow after crossing the louvred panel was almost unnoticeable as the airflow spread quickly throughout the space. Also observed that at lower airflow speeds of 0.5, 1.0, 2.0 and 3.0 m/s, some air at the upper part of the wooden louvred panel did not pass through the louvre slots.

The airflow structure from outdoors to indoors could contribute to the cross and stack ventilation within an indoor space of a building. According to Malaysian Standard (MS 1525:2014) ("MS 2014. Malaysian Standard. MS 1525", 2014), cross ventilation functions by enhancing airflow structure flow through a building caused by a wind-generated pressure drop across it. The warmer air within the building is discharged through the opposite louvred window opening while the cooler outside air enters the building and continuously replaces the warmer air.

Meanwhile, stack ventilation functions by enhancing the flow of airflow structure across space due to air density differences. The warmer air at the upper levels is discharged through the opening near the ceiling. Then, the cooler outside air enters the building through the lower opening (door or window). Stack ventilation is more advantageous in reducing energy than mechanical and air conditioning (Lomas, 2007).

Louvre angle plays a vital role in determining airflow volume and direction into indoor spaces (Aflaki *et al.*, 2015). Chandrashekaran (2010) reported that the volume of airflow passing through indoor spaces is affected by louvre opening angles of 0°, 15° and 30° and that the direction of airflow is affected by a louvre opening angle of 45°. Louvred openings are also the best ventilation for night-time flushing in a tropical climate as they could increase force ventilation (Kubota *et al.*, 2009). A perpendicular louvre window is recommended for natural ventilation systems to increase the pressure inside buildings (Sahabuddin, 2012).

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The results herein indicated that the wooden louvred window panel could continuously replace the indoor air with outdoor air to improve natural ventilation. The proposed panel eliminates the need to open doors and windows for 24 h, thereby offering security. Rasli *et al.* (2019) proposed apertures on window panels to increase the maximum amount of fresh outdoor air moving towards indoor spaces and thereby lower the indoor temperatures and realise proper natural ventilation. The continuation of natural ventilation is vital to reduce the indoor air contaminants that may remain present for years because it aids in diluting the outdoor air that enters buildings (Moreau-Guigon *et al.*, 2016).

At a low airflow speed, the airflow was observed to permeate the window panel slowly, and the airflow structure at the leeward side of the window panel was circulating and broad. As the airflow speed increased, the airflow permeated the wooden louvred window panel extremely fast, and the airflow structure at the leeward side straightened and showed small air motions. The results showed that an increase in airflow speed contributed to the high airflow velocity passing through the wooden window panel and that the airflow filled the indoor space quickly. Ji *et al.* (2018) found that the flow rate of smoke mass increases with the elevated ambient pressure because of the increase in air density and enhanced air entrainment. By contrast, the rate of smoke mass flow decreases with the reduction in ambient pressure, air density and air entrainment, and the heat gain within a building reduced with an increase in air velocity (Sunakorn & Yimprayoon, 2011). With maximum airflow facilitating the air exchange, it can enhance adequate natural ventilation for improved thermal comfort and indoor air quality.

The wooden louvred window panel can protect against the rain splatter. An inclination angle of 75° of the wooden window panel models can help prevent rain splatter from entering the indoor space. As mentioned by Recatala *et al.* (2018), the characteristics of the materials used, the geometry of the external cladding element and the edge profile of joints influence the degree of water tightness of the ventilated façades. This combination can avoid the dampness problem, which causes microbial growth. Rasli *et al.* (2019) reported that microbial growth is strongly dependent on the indoor temperature and

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relative humidity; thus, indoor air quality needs to be maintained at the suggested acceptable limit to protect users from health risks.

4. CONCLUSIONS

Air-conditioning systems typically installed to overcome problems in indoor thermal comfort. However, the systems' air recirculation could contribute to poor indoor air quality and high energy demand and energy cost. Hence, this study aimed to visualise the airflow structure from the outdoors to indoor spaces by using the smoke flow visualisation technique (i.e. smoke generator technique) in a wind tunnel laboratory. The proposed wooden louvred window panel was tested using the smoke generator technique at different airflow speeds of 0.5, 1.0, 2.0, 3.0 and 5.0 m/s. Two Sony 1920 × 1080i cameras were used to capture the side view, rear view, front view and back view images of the airflow structure. The use of wooden louvred window panels improves natural ventilation because it promotes lateral movement of fresh outdoor air continuously. At the highest airflow speed (5 m/s), the proposed wooden louvred window panel can contribute to the optimum replacement of indoor air with outdoor airflow and increase the air exchange rate. The inclination angle of 75° of the wooden louvred window panel can help avoid the rain splatter, and the wood material can be used for façade shading purposes. This work could help address the problems of thermal comfort and indoor air quality and facilitate the development of sustainable buildings. There is also a limitation in this study in which the window panel was not tested for different slot angles, which could determine the best angle for the optimum outdoor air due to the high cost of wind tunnel testing.

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REFERENCES

Aflaki, A., Mahyuddin, N., Awad, Z.A.C.M., & Baharum, M.R. (2014). Relevant indoor ventilation by windows and apertures in a tropical climate, a review study. In *E3S Web of Conferences 3 (01025).* EDP Sciences. https://doi.org/10.1051/e3sconf/20140301025

Aflaki, A., Mahyuddin, N., Awad, Z.A.C.M., & Baharum, M.R. (2015). A review of natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy and Buildings, 101,* 153-162. https://doi.org/10.1016/j.enbuild.2015.04.033

Ahmed, N.A., & Wongpanyathaworn, K. (2012). Optimising louvre location to improve indoor thermal comfort based on natural ventilation. *Procedia Engineering, 49,* 169-178. https://doi.org/10.1016/j.proeng.2012.10.125

Alananbeh, K.M., Boquellah, N., Al Kaff, N., & Al Ahmadi, M. (2017). Evaluation of aerial microbial pollutants in Al-Haram Al-Nabawi during pilgrimage of 2013. *Saudi Journal of Biological Sciences, 24,* 217-225. https://doi.org/10.1016/j.sjbs.2015.08.003

Allocca, C., Chen, Q., & Glicksman, L.R. (2003). Design analysis of single-sided natural ventilation. *Energy and Buildings, 35*(8), 785-795. https://engineering.purdue.edu/~yanchen/paper/2003-11.pdf

Amoatey, P., Omidvarborna, H., Baawain, M.S., & Al-Mamun, A. (2018). Indoor air pollution and exposure assessment of the gulf cooperation council countries, a critical review. *Environment International, 121*, 491-506. https://doi.org/10.1016/j.envint.2018.09.043

Azuma, K., Jinno, H., Tanaka-Kagawa, T., & Sakai, S. (2020). Risk assessment concepts and approaches for indoor air chemicals in Japan. *International Journal of Hygiene and Environmental Health, 225,* 1-9. https://doi.org/10.1016/j.ijheh.2020.113470

https://doi.org/10.17993/3ctecno/2021.v10n3e39.73-99

Bangalee, M.Z.I., Miau, J.J., Lin, S.Y., & Ferdows, M. (2014). Effects of lateral window position and wind direction on wind-driven natural cross ventilation of a building, a computational approach. *Journal of Computational Engineering, 2014,* 1–15. https://doi.org/10.1155/2014/310358

Bayoumi, M. (2017). Impacts of window opening grade on improving the energy efficiency of a façade in hot climates. *Building and Environment, 119,* 31-43. https://doi.org/10.1016/j.buildenv.2017.04.008

Chandrashekaran, D. (2010). *Air Flow Through Louvered Openings, Effect of Louver Slats on Air Movement Inside a Space.* University of Southern California, California, United States, 141.

Cheung, P.K., & Jim, C.Y. (2019). Indoor air quality in substandard housing in Hong Kong. *Sustainable Cities and Society, 48,* 1-10. https://doi.org/10.1016/j.scs.2019.101583

Chu, C.R., Chiu, Y.H., Chen, Y-J., Wang, Y-W., & Chou, C.P. (2009). Turbulence effects on the discharge coefficient and mean flow rate of wind-driven cross-ventilation. *Building and Environment, 44*(10), 2064-2072. https://doi.org/10.1016/j.buildenv.2009.02.012

Chu, C.R., & Wang, Y-W. (2010). The loss factors of building openings for wind-driven ventilation. *Building and Environment, 45*(10), 2273-2279. https://doi.org/10.1016/j.buildenv.2010.04.010

Cui, X., Mohan, B., Islam, M.R., Chou, S.K., & Chua, K.J. (2017). Energy saving potential of an air treatment system for improved building indoor air quality in Singapore. *Energy Procedia, 143,* 283-288. https://doi.org/10.1016/j.egypro.2017.12.685

Robles, D. de, & Kramer, S.W. (2017). Improving indoor air quality through the use of ultraviolet technology in commercial buildings. *Procedia Engineering, 196,* 888-894. https://doi.org/10.1016/j.proeng.2017.08.021

El-Dabaa, R., Abdelmohsen, S., & Mansour, Y. (2020). Programmable passive actuation for adaptive building façade design using hygroscopic properties of wood. *Wood Material Science & Engineering, 16*(4), 246-259. https://doi.org/10.1080/17480272.2020.1713885

Elmualim, A.A. (2006). Effect of damper and heat source on windcatcher natural ventilation performance. *Energy and Buildings, 38,* 939-948. https://doi.org/10.1016/j.enbuild.2005.11.004

Esfeh, M.K., Dehghan, A.A., Manshadi, M.D., & Mohagheghian, S. (2012). Visualized flow structure around and inside of one-sided wind-catchers. *Energy and Buildings, 55*, 545-552. https://doi.org/10.1016/j.enbuild.2012.09.015

Gratia, E., & De Herde, A. (2007). Guidelines for improving natural daytime ventilation in an office building with a double-skin facade. *Solar Energy, 81*(4), 435-448. https://doi.org/10.1016/j.solener.2006.08.006

Hameed, A.A., & Habeeballah, T. (2013). Air microbial contamination at the holy mosque, Makkah, Saudi Arabia. *Current World Environment, 2*(8), 179-187. http://dx.doi.org/10.12944/CWE.8.2.03

Hughes, B.R., & Abdul Ghani, S.A.A. (2010). A numerical investigation into the effect of Windvent louvre external angle on passive stack ventilation performance. *Building and Environment, 45,* 1025-1036. https://doi.org/10.1016/j.buildenv.2009.10.010

Jamaludin, N., Mohammed, N.I., Khamidi, M.F., & Wahab, S.N.A. (2015). Thermal comfort of residential building in Malaysia at different micro-climates. *Procedia-Social and Behavioral Sciences, 170,* 613-623. https://doi.org/10.1016/j.sbspro.2015.01.063

Ji, L., Tan, H., Kato, S., Bu, Z., & Takahashi, T. (2011). Wind tunnel investigation on the influence of fluctuating wind direction on natural cross ventilation. *Building and Environment, 46*(12), 2490-2499. https://doi.org/10.1016/j.buildenv.2011.06.006

Ji, J., Guo, F., Gao, Z., & Zhu, J. (2018). Effects of ambient pressure on transport characteristics of thermal-driven smoke flow in a tunnel. *International Journal of Thermal Sciences, 125,* 210-217. https://doi.org/10.1016/j.ijthermalsci.2017.11.027

Karava, P., Stathopoulos, T., & Athienitis, A.K. (2007). Wind-induced natural ventilation analysis. *Solar Energy, 81*(1), 20-30. https://doi.org/10.1016/j.solener.2006.06.013

Kasim, N.F.M., Zaki, S.A., Ali, M.S.M., Ikegaya, N., & Razak, A.A. (2016). Computational study on the influence of different opening position on wind-induced natural ventilation in urban building of cubical array. *Procedia Engineering, 169*, 256-263. https://doi.org/10.1016/j.proeng.2016.10.031

Kaunelien, V., Prasauskas, T., Krugly, E., Stasiulaitien, I., Ciuzas, D., Seduikyt, L., & Martuzevicius, D. (2016). Indoor air quality in low energy residential buildings in Lithuania. *Building and Environment, 108*, 63–72. https://doi.org/10.1016/j.buildenv.2016.08.018

Krawczyk, D.A., & Wadolowska, B. (2018). Analysis of indoor air parameters in an education building. *Energy Procedia, 147*, 96-103. https://doi.org/10.1016/j.egypro.2018.07.038

Kubota, T., Chyee, D.T.H., & Ahmad, S. (2009). The effects of night ventilation technique on the indoor thermal environment for residential buildings in hot-humid climate of Malaysia. *Energy and Buildings, 41*(8), 829–839. https://doi.org/10.1016/j.enbuild.2009.03.008

Lee, H.M., Lim, K.M., & Lee, H.P. (2016). Experimental and numerical studies of acoustical and ventilation performance of glass louvre window. *Journal of Vibroengineering, 19*(1), 699-706. https://www.jvejournals.com/article/17246

Lei, Z., Liu, C., Wang, L., & Li, N. (2017). Effect of natural ventilation on indoor air quality and thermal comfort in dormitory during winter. *Building and Environment, 125,* 240-247. https://doi.org/10.1016/j.buildenv.2017.08.051

Li, H., Zhu, C., Sun, H., & Feng, G. (2017). Detection and analysis of microbial contamination in museum's constant temperature and humidity air conditioning system. *Procedia Engineering, 205*, 1179-1185. https://doi.org/10.1016/j.proeng.2017.10.188

Lomas, K.J. (2007). Architectural design of an advanced naturally ventilated building form. *Energy and Buildings, 39*(2), 166-181. https://doi.org/10.1016/j.enbuild.2006.05.004

Ma, X.Y., Peng, Y., Zhao, F.Y., Liu, C.W., & Mei, S.J. (2017). Full numerical investigations on the wind-driven natural ventilation, Cross ventilation and single-sided ventilation. *Procedia Engineering, 205*, 3797-3803. https://doi.org/10.1016/j.proeng.2017.10.128

Mohammadmirzaei, M. (2018). *Numerical studies of turbulence effects in cross-flow ventilation.* (4948) [Master's thesis]. San Jose State University. https://doi.org/10.31979/etd.5sf8-8wh8

Montazeri, H., & Azizian, R. (2009). Experimental study on natural ventilation performance of a two-sided windcatcher. Proceedings of the Institution of Mechanical Engineers, Part A, *Journal of Power and Energy, 223*(4), 387-400. https://doi.org/10.1243/09576509JPE651

Moreau-Guigon, E., Alliot, F., Gasperi, J., Blanchard, M., Teil, M.J., Mandin, C., & Chevreuil, M. (2016). Seasonal fate and gas/particle partitioning of semi-volatile organic compounds in indoor and outdoor air. *Atmospheric Environment, 147*, 423-433. https://hal-enpc.archives-ouvertes.fr/hal-01379888

MS 2014. Malaysian Standard. MS 1525. (2014). *Energy efficiency and use of renewable energy for non-residential buildings - Code of practice* (Second revision). Department of Standards Malaysia. Malaysia.

Nahar, N., & Mahyudin, N.A. (2018). Microbiological quality of food contact surfaces (spoons) at selected restaurants in Klang Valley, Malaysia. *Sains Malaysiana, 47*(7), 1541-1545. http://www.ukm.my/jsm/pdf_files/SM-PDF-47-7-2018/23%20Naili%20Nahar%20Isa.pdf

Noman, F.G., Kamsah, N., & Kamar, H.M. (2016). Improvement of thermal comfort inside a mosque building. *Jurnal Teknologi, 78*(5-8), 9-18. https://www.scopus.com/record/display.uri?eid=2-s2.0-84988461374&doi=10.11113%2fjt.v78.9579&origin=inward&txGid=715a47c0eb08e7dcb94f6adbba8ae672

Ocak, Y., Kılıçvuran, A., Eren, A.B., Sofuoglu, A., & Sofuoglu, S.C. (2012). Exposure to particulate matter in a mosque. *Atmospheric Environment, 56,* 169-176. https://doi.org/10.1016/j.atmosenv.2012.04.007

Ohba, M., & Lun, I. (2010). Overview of natural cross-ventilation studies and the latest simulation design tools used in building ventilation-related research. *Advances in Building Energy Research, 4*(1), 127-166. https://doi.org/10.3763/aber.2009.0405

Ohba, M., Irie, K., & Kurabuchi, T. (2001). Study on airflow characteristics inside and outside a cross-ventilation model and ventilation flow rates using wind tunnel experiments. *Journal of Wind Engineering and Industrial Aerodynamics, 89*(14-15), 1513-1524. https://doi.org/10.1016/S0167-6105(01)00130-1

Rasli, N.B.I., Ramli, N.A., Ismail, M.R., & Shith, S. (2019). Dependency of Biological Contaminants on Temperature and Relative Humidity within Praying Halls of Mosques. *Sains Malaysiana, 48*(8), 1575-1581. http://www.ukm.my/jsm/pdf_files/SM-PDF-48-8-2019/02%20Nur%20Baitul%20Izati%20Rasli.pdf

Rasli, N.B.I., Ramli, N.A., Ismail, M.R., Faizah, N.F.M.Y, Shith, S., Kamaruddin, N.M., Salleh, M.B., & Nazir, A.U.M. (2019). Smoke flow visualisation testing on window panel at various wind speed and pores, a wind tunnel study. *Journal of Sustainability Science and Management, 14*(6), 66-79. https://jssm.umt.edu.my/wp-content/uploads/sites/51/2019/12/7-14.6.pdf

Recatala, M.A., Morales, S.G., & van den Bossche, N. (2018). Experimental assessment of rainwater management of a ventilated façade. *Journal of Building Physics, 42*(1), 38-67. https://doi.org/10.1177/1744259117719077

https://doi.org/10.17993/3ctecno/2021.v10n3e39.73-99

Sahabuddin, M.F.M. (2012). *Traditional Values and Their Adaptation in Social Housing Design, Towards A New Typology and Establishment of 'Air House' Standard in Malaysia'.* The University of Edinburgh, UK. https://www.academia.edu/2040487/IJAR_-_Traditional_Values_and_Their_Adaptation_in_Social_Housing_Design_Towards_A_New_Typology_and_Establishment_of_Air_House_Standard_in_Malaysia_

Spiru, P., & Simona, P.L. (2017). A review on interactions between energy performance of the buildings, outdoor air pollution and the indoor air quality. *Energy Procedia, 128,* 179-186. https://doi.org/10.1016/j.egypro.2017.09.039

Steinemann, A., Wargocki, P., & Rismanchi, B. (2017). Ten questions concerning green buildings and indoor air quality. *Building and Environment, 112,* 351-358. https://doi.org/10.1016/j.buildenv.2016.11.010

Sun, Y., Wang, P., Zhang, Q., Ma, H., Hou, J., & Kong, X. (2015). Indoor air pollution and human perception in public buildings in Tianjin, China. *Procedia Engineering, 121*, 552-557. https://doi.org/10.1016/j.proeng.2015.08.1032

Sunakorn, P., & Yimprayoon, C. (2011). Thermal performance of bio facade with natural ventilation in the tropical climate. *Procedia Engineering, 21,* 34-41. https://doi.org/10.1016/j.proeng.2011.11.1984

Vailati, C., Bachtiar, E., Hass, P., Burgert, I., & Rüggeberg, M. (2018). An autonomous shading system based on coupled wood bilayer elements. *Energy and Buildings, 158,* 1013-1022. https://doi.org/10.1016/j.enbuild.2017.10.042

Yakubu, G.S., & Sharples, S. (1991). Airflow through modulated louvre systems. *Building Services Engineering Research Technology, 12*(4), 151-155. https://www.aivc.org/sites/default/files/airbase_5405.pdf

https://doi.org/10.17993/3ctecno/2021.v10n3e39.73-99

Yu, S., Yu, Z., Ma, X., Zhang, G., & Feng, G. (2017). Study on the influence of pollution source location on indoor pollutant distribution under different air supply. *Procedia Engineering, 205,* 2623-2630. https://doi.org/10.1016/j.proeng.2017.10.204

Zhong, K., Yang, X., Feng, W., & Kang, Y. (2012). Pollutant dilution in the displacement of natural ventilation rooms with inner sources. *Building and Environment, 56,* 108-117. https://www.semanticscholar.org/paper/Pollutant-dilution-in-displacement-natural-rooms-Zhong-Yang/501210e7f7f48a7ebf08ed88b6bfe1f87a416f68

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NON-LINEAR MODELLING OF FERRO CASTING DUCTILE SHEAR KEY OF L-SHAPED CONCRETE BLOCKS WITH EPOXY JOINT USING MIDAS FEA

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ABSTRACT

As cast iron with 10-15% of graphite, Ferro Casting Ductile (FCD) Iron material has better mechanical properties than the ones from Grey Cast Iron. Moreover, it is also close to Carbon Steel's properties. Regarding this condition, FCD has the potential to be used as a shear key, specifically, as a joint of precast segmental concrete bridges. The objective of this paper is to study the mechanical behavior of FCD applied as shear key on a wet precast joint using epoxy. To do so, three-dimensional non-linear numerical modeling using Midas FEA was conducted on two L-shaped concrete blocks connected by a couple of FCD shear key representing precast concrete segmental bridge system. Between these two L-shaped blocks of concrete, epoxy adhesive was ap-plied. Both concrete blocks and FCD shear keys with 50% scale of original geometries were used. The constitutive behavior of each material was obtained from previous test results and literatures. Loading applications were performed in two directions, vertical load to represent load from deck bridge and horizontal load to represent prestressing force. Load bearing capacity of FCD shear keys increases along with the increase of horizontal load. Non-linear analysis results show discrepancy comparing to the exper-imental ones, with a deviation reaches more than 7%.

KEYWORDS

Ferro Casting Ductile, Male and Female Shear Keys, Force-Displacement Relations, Numerical Simulation.

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1. INTRODUCTION

Shear keys are prominently used in the joints of precast segmental concrete bridges. Prior to the use of metal shear keys, concrete shear keys have been used nowadays. The ultimate strength at the joint of precast concrete girders depends on the behav-ior of the material of joints between segments. The behavior of shear key joints, whether using concrete or metal as their primary material, has been a subject of several experimental studies in the past.

One of the studies is an experimental work by Zhou, Mickleborough and Li (2005). They studied the behavior of shear strength of joints in precast concrete segmental bridges. Several type of concrete shear keys such as flat shear keys, multiple shear keys, with and without epoxy have been ana-lyzed experimentally to investigate the shear capacity of each key in different kinds of joints. From this study, it is found that the shear strength of the joints increases with an increase in confining stress. Moreover, their experimental study stated that dry joints had an ultimate strength of approximately $20-40\%$ less than epoxied joints.

Yuan *et al.* (2019) studied the shear behavior of epoxy resin joints with plain concrete shear keys, reinforced shear keys, internal post-tensioned tendon shear keys and concrete shear keys with inclined design. Following the experimental study that has been conducted by Yuan *et al.* (2019), several results found that reinforced shear keys and internal post-tensioned tendon shear keys with epoxy resin joints generates a superior performance in ductility behavior than any other type of shear keys test-ed in the experiment.

A series of tests resulted in a different epoxy resin joint failure mode for each design parameters. Epoxy joint with plain concrete shear keys exhibited typical shear off along the key base, reinforced shear keys demonstrated concrete covers crushed off over the reinforcing bar, meanwhile internal post-tensioned shear keys revealed cracks propagated deeply into the male and female specimens. The Japanese standard (Japan Society of Civil Engineering, 2007) recommends the use of FCD (ferro casting ductile) metal

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with grade 450 as a material for FCD shear keys. The Japa-nese standard's recommendation was verified by Purnomo *et al.* (2017) in their ex-periment.

Purnomo *et al.* (2017) found that shear keys with grade 450 have higher shear strength with the smallest displacement than any other FCD metal with grade range from 265-274 MPa (Compression yield stress). Purnomo *et al.* (2018) have conducted experiments with specific geometry shear key and different geometry shear keys. The geometry shear key used in this paper is also one of the types of shear keys which has been used by Purnomo and others in previous experiments. The methodology of the non-linear models closely resembles the methodology in Purnomo and others' experimental study.

In this numerical study, non-linear analysis is performed by using two L-shaped concrete blocks representing precast concrete segmental bridge system. These two blocks are connected by male shear key in top of concrete blocks and female shear keys in bottom of concrete blocks. One layer of epoxy with thickness 1 mm is ap-plied between concrete blocks as representative of epoxy connection type in joint of concrete blocks. Pinned support is placed at the bottom of concrete blocks as its boundary condition. Afterwards, increment vertical load is mounted at top of upper concrete block to represent load which occur on top joint segmental concrete gird-ers. The horizontal load is applied at left of upper concrete blocks as representative of prestress force. The constitutive law applied for the nonmetal materials are the Total Strain Crack Model (T-S Crack Model).

2. METHODOLOGY

2.1. NON-LINEAR APPROACH

The non-linear analysis is made to simulate similar experimental test setup in pre-vious studies (Purnomo *et al.*, 2017; 2018). The configuration of the test setup of precast concrete girder uses two concrete blocks as shown in Figure 1. The two con-crete block itself are set in a test frame which is equipped with two hydraulic pumps. One of the two hydraulic pumps is placed above the concrete blocks with

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vertical orientation to represent the incremental load which compresses the concrete block. Another one is placed in the center, beside the concrete block, with horizontal orien-tation to represent the equivalent prestress force. Four digital gauges are located uniformly in the vertical direction to record the vertical displacements in front and at the back of the concrete block. The correlation between the load and displace-ment is obtained from the recording of the load cell placed above the concrete block to represent incremental load and from the average of result from the four digital gauges to represent displacement.

Figure 1. Laboratory Test Set-Up.

Source: own elaboration.

2.2. SHEAR KEY GEOMETRY AND MATERIAL PROPERTIES

The male and female shear keys are made of Ferro casting ductile with material grade of FCD 450. The concrete blocks are made of reinforced concrete with a 28-days compressive strength of 41.2 MPa, which is representative of the confined compressive strength of precast concrete girders.

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The geometry of the shear keys modeled in Midas FEA is presented in Figure 2. The male shear key is described in blue color. On the right side of Figure 2. is the female part of the shear key joint.

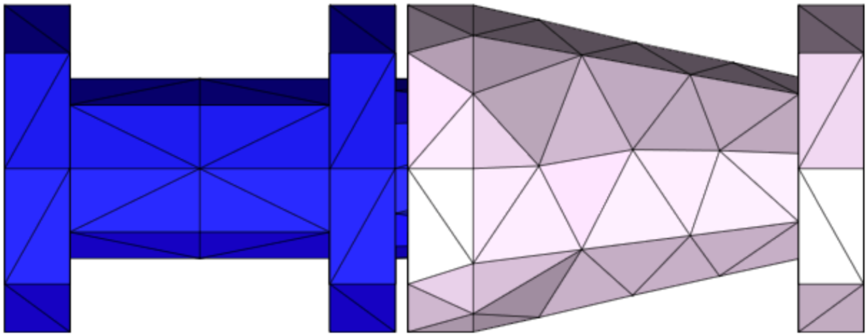

Figure 2. Geometry of the Male and Female Shear Keys (K1) in Midas FEA.

Source: own elaboration.

The dimensions of the concrete blocks and shear keys used in the test are shown in Figure 3. The numerical analysis uses a model of concrete blocks and shear keys with fifty percent downscaling in geometry. The geometry of the concrete blocks and shear keys are modeled using Autodesk inventor separately. The joint, made of ferro casting ductile shear keys, are located at the vertical midpoint of the upper concrete block and are casted into the female shear keys and bottom concrete block. The upper concrete block is mounted 10 mm higher than bottom concrete block. The vertical gap in between the concrete blocks is filled with epoxy joint with a thickness of 1 mm.

Corresponding to the experimental study, vertical loads are applied as incremental load while the horizontal load needs to be maintained as linear load throughout the duration of the experiment. Due to limitations in the loading application setting in Midas FEA, the program cannot distinguish the two loads with different step of loading.

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Two numerical models are created in Midas FEA. The first model is a linear analy-sis model with only horizontal load is applied. This first model is used to identify the effects of horizontal load, which represents the prestressing force on the concrete block. The horizontal load is modeled in a linear model where its shear stress is ex-tracted and applied as additional shear stresses of the epoxy joint and concrete. The second model is a non-linear analysis model with incremental vertical displace-ments. The non-linear model considers the additional shear stress from the first model which is applied to shear stress of epoxy joint and concrete.

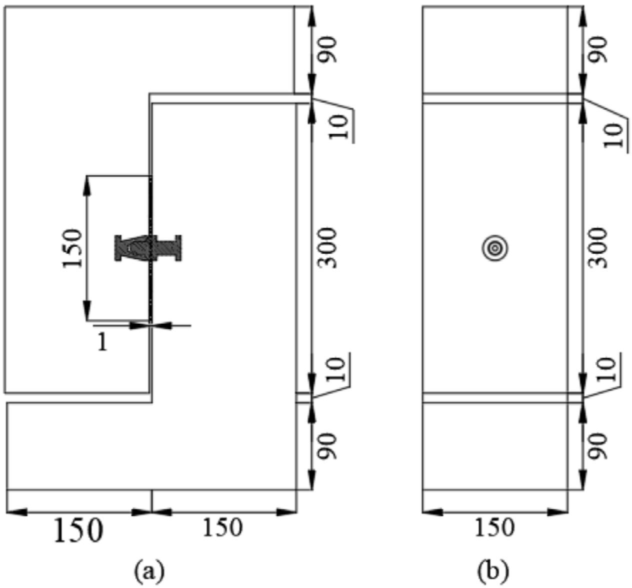

Figure 3. Dimensions of the Concrete and Shear Key Models. (a) Front view, (b) Cross Section View.

Source: own elaboration.

The engineering data of each of the materials in the joint precast concrete girders have been measured in the laboratory. The compressive stress-strain relationship of concrete obtained from cylindrical compressive strength test are acquired from the internal data of Structural and Material Laboratory

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of Universitas Indonesia ("Ma-terials Test Result Internal Data of Structural Laboratory at Universitas Indone-sia", 2020). The tensile strength of concrete model uses the formula obtained from Hu, Lin and Jan (2004). In addition, the shear strength of concrete and the com-pressive, tensile and shear strength of epoxy are obtained from the internal data of Structural and Material Laboratory of Universitas Indonesia ("Materials Test Re-sult Internal Data of Structural Laboratory at Universitas Indonesia", 2020). The compressive and tensile stress-strain relationship of ferro casting ductile are also obtained from the laboratory. The stress -strain relation for FCD Material of each behavior is shown in Figure 4. The Poisson's ratio of concrete, ferro casting ductile and epoxy use the values 0.2, 0.28, and 0.35, respectively.

The constitutive law for nonmetal material of numerical models uses Total Strain Crack model which is provided by Midas FEA. Meanwhile, failure behavior of each material uses different constitutive law. The maximum shear strength of the joint is measured by either the tensile failure of the concrete or the yielding of the shear keys. The epoxy joint can increase the shear capacity of the joint if applied with a proper thickness. The tensile failure of the concrete is assumed to be the maximum principal stress or Rankine's theory (Boresi & Schimdt, 2003). Rankine's theory is assumed to occur when the maximum principal stress at any point reaches a value equal to the tensile stress of a simple tension specimen at failure. Correspondingly, the tensile failure at the upper concrete block occurs when the maximum principal stress reaches the tensile strength of concrete. Meanwhile, the failure criterion of ferro casting ductile shear key use the Von Mises criterion. Based on the Von Mises criterion, the yielding of the shear key occurs when the equivalent stress of a mate-rial under load is equal or greater to its yield limit (Boresi & Schimdt, 2003).

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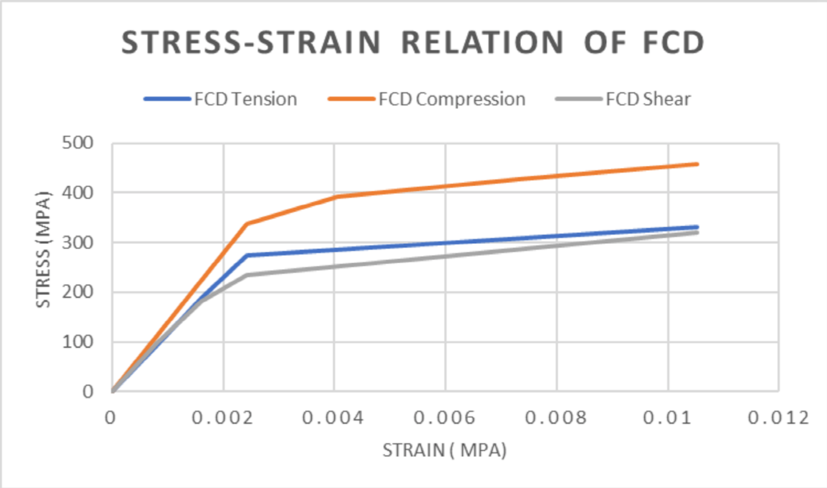

Figure 4. Stress-Strain Relationship for FCD Material.

Source: own elaboration.

In the following Table 1, stress representing prestress applied on the system as hori-zontal load is presented. Two different horizontal forces were used to examine and to find the adequate configuration of shear key and concrete block which produces the maximum shear capacity. These values are applied in the 1st numerical model-ling.

Table 1. FEA Analysis Variation.

Variation	Initial Stress (MPa)
K1P3	0.345
K1P6	0.69

Source: own elaboration.

The finite element model uses three-dimensional simulation in Midas FEA. Solid element with Total strain crack mode was used as the consecutive model of three primary materials. Contact between the concrete-shear key and the epoxy was de-fined as rigid contact with symmetric condition. Rigid contact

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is considered to be the contact between the shear key and concrete. Pinned boundary condition for the transversal axis is applied to the base of bottom concrete block. The upper concrete block was set free with no boundaries. Vertical displacements were applied above the upper concrete block. The vertical displacements are assigned in a 150x150 mm2 area incrementally. The horizontal load area is located on the left side of the upper concrete block. Two models of numerical analysis are schematically shown in Figure 5.

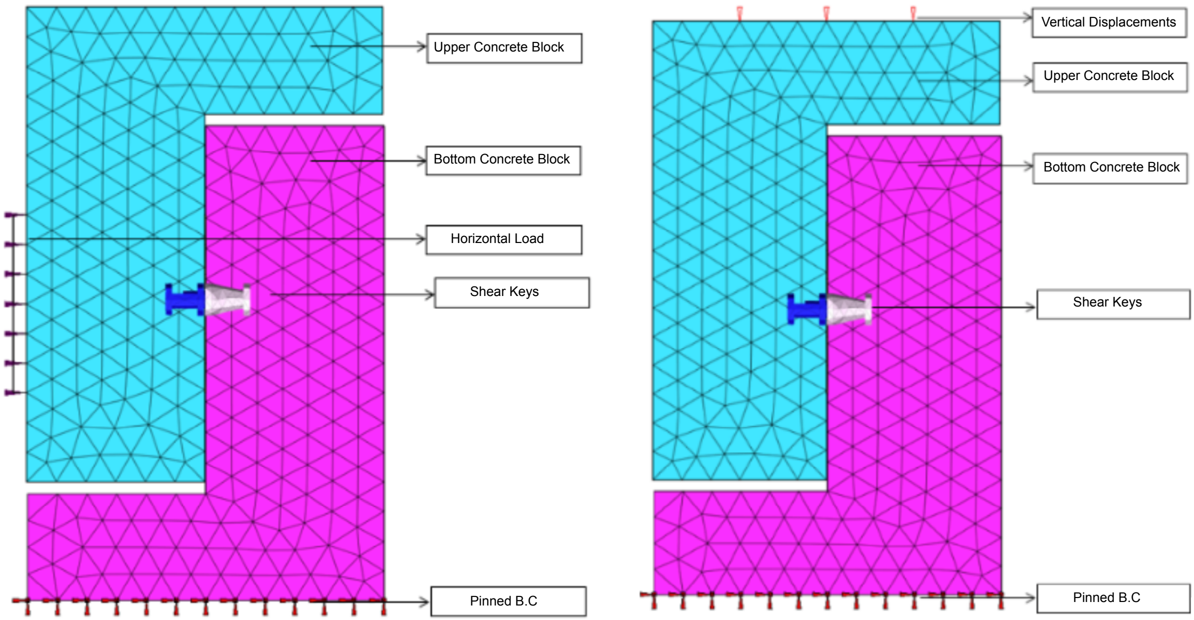

Figure 5. Linear and Non-Linear Models on Midas FEA. (a) 1st Model for Linear Analysis with Horizontal Load, (b) 2nd Model for Non-Linear Analysis with Vertical Load.

Source: own elaboration.

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3. RESULTS

3.1. MAXIMUM LOAD CAPACITY OF JOINTS

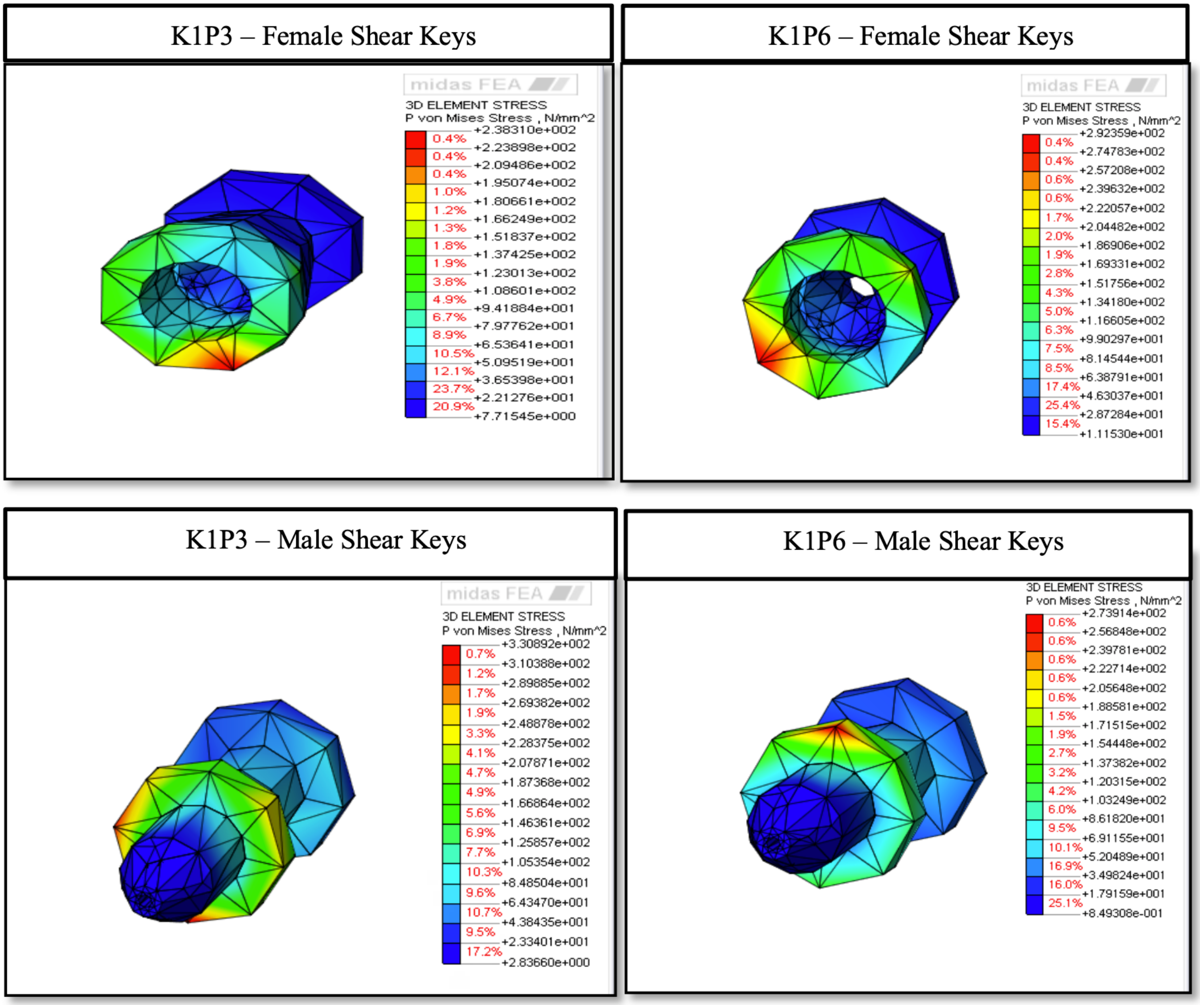

Figure 6. Von Mises Stress Contour in Male (Upper) and Female (Bottom) Shear Keys.

Source: own elaboration.

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Figure 6 displays the contour of Von Mises stress of each shear key with different initial stresses prior to reaching its maximum vertical load. Following the displayed contour of Von Mises stress, it can be seen that the male shear keys in every initial stress condition demonstrate the highest concentration of stress at the outer ring of the shear key. The highest concentration of stress of the female shear keys follows the male shear keys. The highest Von Mises stress of shear key is generated by vari-ation K1P3 with 331 MPa and K1P6's Von Mises Stress is 274, Meanwhile Female shear key of K1P6 exhibit greater stress than K1P3's Female shear key. The max-imum value of Von Mises Stress for each model exceeded the yield stress of ferro casting ductile shear key. The comparation of stress- strain relationship between two models is shown in below Figure 7. Based in graphic in Figure 7 maximum loads occurred in K1P6 greater than K1P3. The deviation between two models maximum load reach 37%.

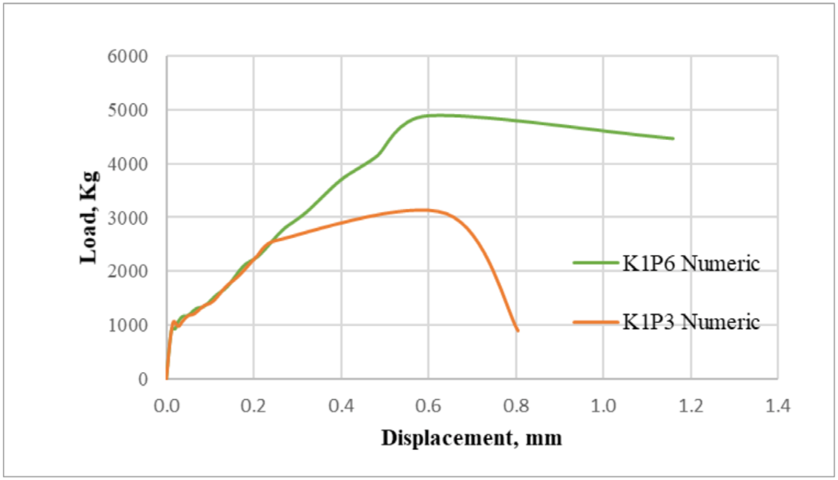

Figure 7. Load-Displacements Relationship of Shear Keys.

Source: own elaboration.

In Figure 7, K1P3 exhibit the lowest maximum vertical load which can be received by the concrete block. K1P6 exhibit ductile behaviour while K1P3 demonstrated brittle behaviour after reaching its maximum value, the graphic shows the load plunges after reaching the maximum load. In K1P6, the loads are decreasing after reaching its maximum value with displacement almost twice the displacement

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of maximum value. In accordance with these results, horizontal forces can affect the joint system. The maximum load demonstrates better value along with the in-creased horizontal force.

3.2. COMPARISON BETWEEN EXPERIMENT RESULTS AND NUMERICAL ANALYSIS

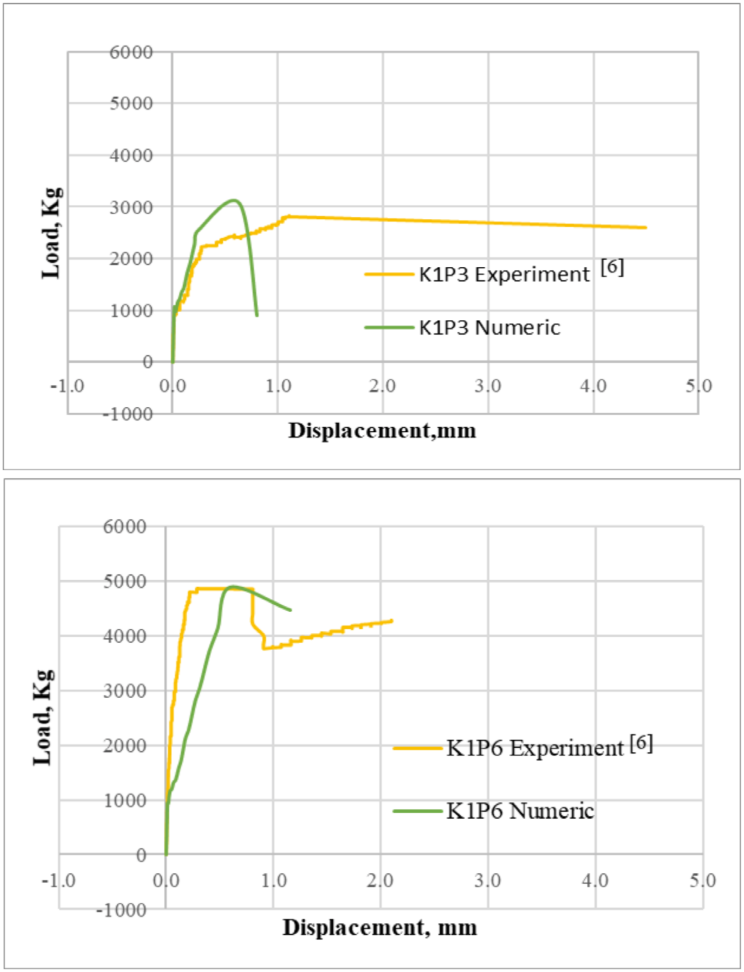

Figure 8. Comparison of Load-Displacement Relationship between Experiment Results and Nu-merical Analysis.

Source: own elaboration.

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Referring to Figure 8, comparing the graphic of load-displacement relation from experiment results and numerical analysis, the results are very disparate. For both models, failure occur due to brittleness. Therefore, the loads drop after reaching their maximum value. The different results between the experimental results and numerical analysis are due to several occasions that happened during the experiment. For example, an equal application of epoxy thickness between the concrete blocks is quite hard to achieve in experiment. Meanwhile, in the numerical model, thickness of epoxy can be arranged equally. The percentage value of deviation for each model are shown in Table 2. The minimum deviation occurs in the K1P6 model.

Table 2. Comparison of Results between Experiment and Numerical Analysis.

Variation	Max Displacement (mm)		Deviation	Max Force (Kg)		Deviation
	Experiment	Numeric	(%)	Experiment	Numeric	(%)
K1P3	1.11	0.64	42%	2830	3066	8%
K1P6	0.29	0.60	111%	4870	4883	0%

Source: own elaboration.

4. CONCLUSIONS

Based on the numerical modelling of shear key and precast concrete block joint, it can be concluded that the maximum load capacity of the joint system occurs ac-cordingly with the increase of horizontal force. Following the contour of Von Mises stress, it can be seen that the highest stress is localized at the counter part of female shear keys of model K1P6. The results of experiment and numerical studies show different results due to limitation of application on experiments study and limita-tions of numerical study program. The load vs displacement curves obtain from numerical study are compared with the result of the experimental study. The choice of tensile stress-strain model for the concrete in the TS Crack Model affect the maximum load obtained by the numerical simulation. The experimental and nu-merical curves matched sufficiently up to before the rupture of epoxy layer, to be precise at the elastic linier region. Once it behaves non-linearly, passing 1000 kg of loading application, only K1P3 sample

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could exhibit close mechanical behavior to the experimental results. Furthermore, in case of K1P3, passing 2200 kg of loading application, the result of experiments and simulations are very different. It seems the damage in the system concrete blocks and shear key occurred largely. In the future works, the modelling can be improved, such as consideration of damage con-dition after the post peak of loading application.

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REFERENCES

Boresi, A. P., & Schimdt, R. J. (2003). *Advanced Mechanics of Materials* (6th ed.). John Wiley & Sons, Inc.

Hu, H.-T., Lin, F.-M., & Jan, Y.-Y. (2004). Nonlinear Finite Element Analysis of Reinforced Concrete Beams Strengthened by Fiber-Reinforced Plastics. *Composite Structures, 63*(3-4), 271-281. https://doi.org/10.1016/S0263-8223(03)00174-0

Japan Society of Civil Engineering. (2007). *Standard Specifications for Concrete Structures "De-sign"*. JSCE Guidelines for Concrete No. 15. https://www.jsce-int.org/system/files/JGC15_Standard_Specifications_Design_1.0.pdf

Materials Test Result Internal Data of Structural Laboratory at Universitas Indonesia. (2020). https://www.ui.ac.id/en/

Purnomo, H., Nursani, R., Mentari, S., Rahim, S. A., & Tjahjono, E. (2017). Numerical Evaluation of the Shear Behaviour of a Metal Shear Key Used in Joining Precast Concrete Seg-mental Bridge Girders without Epoxy. *International Journal of Technology, 8*(6). https://ijtech.eng.ui.ac.id/article/view/711

Purnomo, H., Orientilize, M., Nursani, R., & Hardjanto, F. (2018). Numerical Modelling and Simulation of Ferro Casting Ductile Shear Keys for Precast Concrete Girders. In *ICCMS 2018: Proceedings of the 10th International Conference on Computer Modeling and Simu-lation*, pp. 253-257. https://doi.org/10.1145/3177457.3177479

Yuan, A., Yang, C., Wang, J., Chen, L., & Lu, R. (2019). Shear Behaviour of Epoxy Resin Joints in Precast Concrete Segmental Bridges. *Journal of Bridge Engineering, 24*(4). https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29BE.1943-5592.0001362

Zhou, X., Mickleborough, N. C., & Li, Z. (2005). Shear Strength of Joints in Precast Concrete Segmental Bridges. *ACI Structural Journal, 102*(1), 3-11. https://www.researchgate.net/publication/285773797_Shear_strength_of_joints_in_precast_concrete_segmental_bridges

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tecnología

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